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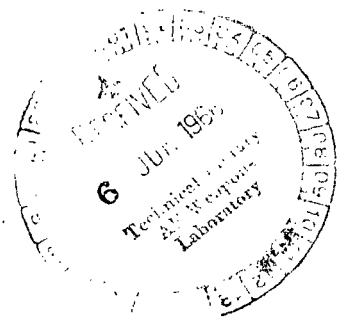


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EXPERIMENTAL MEASUREMENT OF OPTICAL ANGULAR DEVIATION CAUSED BY ATMOSPHERIC TURBULENCE AND REFRACTION

by Robert L. Kurtz and James L. Hayes

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NOMENCLATURE

H	= Horizontal
R	= Receive
T	= Transmit
V	= Vertical
$\bar{\sigma}$	= Sample mean
σ_{comp}	= Composite standard deviation of the combined sets
σ_i	= Rms for 0 to 15 Hertz
μ	= Mean of composite amplitude density
μ_i	= Mean of individual amplitude density
n	= Number of observations
s	= Sample standard deviation

EXPERIMENTAL MEASUREMENT OF OPTICAL ANGULAR DEVIATION CAUSED BY ATMOSPHERIC TURBULENCE AND REFRACTION

SUMMARY

Atmospheric turbulence causes the image of a stationary optical source to fluctuate in intensity and position. The amplitude and frequency of this random position fluctuation have been measured. Data were recorded over a period of approximately six months and over two different path lengths. The system and site are described. Data are analyzed and tabulated to show the amplitude of fluctuations in various meteorological conditions. A sample of these data is statistically analyzed to determine the limitations of an optical tracking system.

INTRODUCTION

Turbulence between the optical transmitting point and receiving system causes the image of that point to blur and to fluctuate in position and intensity. This random position fluctuation causes a stationary source to appear to move over a finite area with a varying amplitude and frequency. The accuracy of locating this source in space is limited by the varying amplitude of the fluctuations. Measurements of these fluctuations were taken over two path lengths: Case I path length of 3,200 m; Case II path length of 165 m. The magnitudes of angular deviation vary with the frequency of atmospheric fluctuations. For Case I, the highest magnitudes of fluctuations occur for the frequency range 0 to 50 Hz; for Case II, 0 to 10 Hz. The magnitudes of angular fluctuations are down by a factor of at least two, typically after 50 Hz for Case I and after 10 Hz for Case II. For Case I, the composite rms fluctuation for 0 to 150 Hz range is approximately twice the composite rms fluctuation for the range 0 to 15 Hz. For Case II, the composite rms fluctuation of 0 to 150 Hz is approximately 1.5 times that of 0 to 15 Hz. The rms fluctuations for 0 to 15 Hz range for Cases I and II are found in Tables I and II, respectively. For a factor-of-20 difference in path length of the two cases, their mean amplitude of fluctuation varied by a factor of 1.7.

The purpose of this paper is to present measurements of amplitude and frequency of these apparent angular deviations taken over a period of approximately six months under varying atmospheric conditions. A further purpose is

to present the statistical evaluation of a selected range of these data, 0 to 15 Hz, needed to determine the system limitations of the precision optical tracking system for advanced launch vehicles (POTSALV) being developed by this agency.

PURPOSE OF THE EXPERIMENT

The development of an optical radar system (POTSALV) by this laboratory necessitates a knowledge of the error in position measurement caused by the apparent angular deviation of a 6328Å laser beam by atmospheric turbulence. The frequency range of atmospheric fluctuations from 0 to 15 Hz is of primary concern because fluctuations in this range will affect the design of the tracking-mount servo system. This frequency range was selected because vehicle vibrations greater than 15 Hz will be of negligible amplitude as far as the optical tracker is concerned.

The measured frequency range, 0 to 150 Hz, was recorded from a secondary interest. A statistical or mathematical model capable of predicting angular deviations when atmospheric parameters are known is desired. These data, over the frequency range of 0 to 150 Hz, along with corresponding atmospheric data and additional data taken under other conditions, will be used later in an effort to establish a statistical model.

EXPERIMENTAL SITE

Data on atmospheric fluctuations were taken over two different path-lengths. The elevation angle of both paths was approximately 4 degrees with the receiving telescope approximately two meters above ground level. Both paths were over varying types of terrain and ground cover. The longer path, Case I, was 3200 m $\pm 1\%$; the shorter path, Case II, was 165 m $\pm 1\%$, or a difference factor of about 20 in distance. The transmission path of Case I lay in a northeasterly direction; that of Case II in a westerly direction (Figs. 1 and 2).

A 6328Å gas laser signal was transmitted over the paths of Case I and Case II, where it was incident on a 9 cm aperture Questar telescope housed in an observation dome. The Questar sharply focused the energy of the accepted cone onto the cathode of the star tracker tube. The signal processing will be described later.

ATMOSPHERIC DETECTION SYSTEM

Surface stations furnished by NASA's meteorological division consisted of the following equipment for the measurement of relative pressure, humidity and temperature, and wind velocity.

Frietz Microbarograph
Frietz Hygrothermograph - Model 594
Frietz Anemometer (Propeller type).

These instruments were chart recording devices.

For Case I, one surface station was at the transmitting site and one at the receiving site. In each station the instruments were near the path of transmission. The chart recorders allowed a time average of the parameters from each station. For Case II only one station at the receiving site was used because of the short transmission path and the difficulty of placing a station at the transmission point.

DESCRIPTION OF THE SIGNAL DETECTION SYSTEM AND THE METHOD OF SIGNAL PROCESSING

Transfer Curve

The measuring system causes a sensitive area to scan over the cathode of a star tracker tube in a cruciform pattern. When the focused spot is in the center of the scan pattern, no error signal is developed and consequently no output voltage. As the spot moves laterally off the center of the scan pattern, increasing error signal is developed and with it a larger output voltage. This output voltage is proportional to the angle of deviation. This proportionality is shown by the transfer curve (Fig. 3), which was determined in the following manner. The transmitting and receiving systems were placed a known distance apart. The transmitter was displaced a small distance Δd laterally from, and perpendicular to, the direction of transmission. This movement produced an error signal and an output voltage that was proportional to an angle α with respect to the optical axis of the system.

System Operation

A block diagram (Fig. 4) shows a remotely located laser source transmitting 6328Å radiation through a turbulent atmosphere. The 6328Å beam, with the angular deviations imposed on it, is accepted by the Questar telescope. This

energy is sharply focused onto the cathode of the star tracker tube which is electrostatically focused. An internal aperture defines a small area of sensitivity on the tube's cathode. This area is swept over a wider area of the cathode in a cruciform pattern by a quadrature magnetic field imposed by a coil around the neck of the tube. The magnitude and frequency of the apparent angular deviations of an optical source are detected as a result of the displacement of the source's image from the center of this cruciform pattern. The position of the focused spot off the center of the cruciform scan pattern produces a signal which is then applied to a squaring amplifier and automatic gain control (AGC) network. On applying this output to the digital phase discriminator, the signal is phase compared to a square wave clock pulse and an output voltage is developed. The outputs are voltages in two channels proportional to an angle taken with respect to the system's optical axis. The two channels represent angular deflections in the horizontal and vertical axes. This fluctuating output voltage is low-pass filtered from 0 to 150 Hz and recorded on magnetic tape.*

Signal Processing Procedure and Equipment

1. The data, recorded on magnetic tape at 7.5 IPS, were processed by the Noise Analysis Section of Astrionics Laboratory.** The frequency spectrum analysis was performed (Fig. 5a) giving the amplitude versus frequency range of 2 to 150 Hz, with an effective analyzer filter bandwidth of about 1 Hz. To do this the tape-speed-up method was used; the speed-up factor was 16. The values on the Technical Products analyzer graphs refer to the original frequency. Amplitude values are calculated for an analyzer filter bandwidth of 1 Hz.

A representative section of data was selected from each run and recorded on a continuous tape loop. By employing this method, a typical signal of long duration suitable for the slow-sweeping analyzer is obtained.

The loop length chosen is 4 seconds ($16 \times 4 = 64$ seconds of original data). The effective analyzer filter bandwidth is 13 Hz, which allows a resolution of $13/16$ Hz, which is normalized to a 1 Hz bandwidth.

*Acknowledgement is given to Mr. Bill Dunn for his efforts in the design and fabrication of the signal detection system.

**Acknowledgement is given to Messrs. Heinrich Hahn, K. D. Rudolph, and Paul Martin for their work in processing this volume of data.

The signal from the tape recorder/reproducer is heterodyned with the signal of the swept oscillator. The difference of the "loop" signal and the oscillator signal is received by a bandpass filter. The signal from the filter is fed to the averager network and recorded on the x-y recorder.

2. The amplitude density curves are found through additional processing of the continuous tape loop of the initial raw data (Fig. 5b). The raw data recorded on the magnetic tape loop are low-pass filtered from 0 to 15 Hz. The filtered signal is fed to an amplifier which is gain adjusted to allow an output of 1 volt rms, thus normalizing each signal to an rms of 1 volt, i.e., a normalized σ . Using a voltage window of interval width ΔV , the probability density analyzer (PDA) sweeps through the filtered 0 to 15 Hz signal from $+5\sigma$ to -5σ . As more amplitudes occur in interval ΔV , voltage increases and the individual amplitude density plot is produced (Fig. 5b).

For further detailed information on the processing procedure, refer to Reference 1.

PRESENTATION OF DATA

Procedure

The apparent position fluctuation of the 6328Å laser source was recorded as a fluctuating voltage on magnetic tape. Angular deviations were measured for two cases; Case I has a transmission path length approximately 20 times longer than Case II. The amplitude (V rms) versus frequency plot of this information shows magnitude of angular variations with frequency of fluctuations. Amplitudes of frequencies of fluctuation up to 150 Hz were measured. The frequency region of primary interest was 0 to 15 Hz, since vehicle vibration frequencies greater than 15 Hz have negligible amplitude from the tracking system's point of view. Only this frequency region of primary interest is analyzed statistically. The analysis produced (1) the distribution of individual rms (σ_1) values about their mean, affording a probability prediction about the limit of rms value, and (2) the composite amplitude density distribution from individual amplitude density distributions, affording a probability prediction of limit of peak value.

Data Analysis

Case I. - Data from individual runs are recorded on magnetic tape. Oscillograph examples of individual run variation are given in Figure 6. These raw data, when processed as described on page 4, produce the amplitude (V rms) versus frequency of fluctuation normalized to a 1 Hz bandwidth (Figs. 8 through 17). (All amplitude values are in volts rms. Conversion to angle in micro-radians is effected through the transfer curve (Fig. 3)). An attempt to correlate these fluctuations with atmospheric parameters divided the amplitude-versus-frequency curves naturally into two major groups, Group I and Group II, when the shape of the frequency region 50 to 150 Hz is considered. Consideration of the peak shape (0 to 50 Hz) subdivides the groups as follows.

<u>Group I</u>	<u>Group II</u>
Curves A	Curves C
Curves B	Curves D
	Curves E.

Sketches of the shape of these curves and two typical examples of each curve are presented in Figures 7 through 17. When the composite rms value of the total runs was calculated for the 0 to 15 Hz range, all of the minima fell in Group II. Considerable overlap of composite rms existed between the two major groups, however, and is demonstrated in the histogram of Figure 18. Angular deviations along horizontal and vertical axes were measured. While the rms mean of the vertical was $16.2 \mu\text{rad}$ and that of the horizontal was $15.3 \mu\text{rad}$, neither one was consistently larger than the other. Therefore, in the grouping, the horizontal and vertical deviations are considered collectively.

The selected region of interest, 0 to 15 Hz, was considered over three successive 5-Hz intervals W , producing three values of amplitude A . These three amplitude values were used to calculate the individual rms σ_i of the corresponding amplitude densities.

Using

$$\sigma_i = \text{rms} = \left[\sum_i (A_i)^2 (W_i) \right]^{\frac{1}{2}} \quad (1)$$

where A_i = amplitude

W = interval width

σ_i = rms for 0 to 15 Hz

the individual σ_i (rms) was calculated for all 55 runs and is tabulated in order of increasing magnitude in Table I. Calculated rms compared to measured rms to within 5 percent.

From the σ_i (rms) values of Table I, a frequency histogram was prepared (Fig. 19). This histogram presents the combined data from horizontal and vertical measurements, each of which is considered an independent observation. The total of 55 observations constitutes one sample. The sample mean and sample standard deviation of this distribution were computed as follows.

$$\text{Sample mean } \bar{\sigma} = \frac{\sum_{i=1}^n \sigma_i}{n} \quad (2)$$

where

n = total number of samples

σ_i = rms values (Table I)

and

$$\bar{\sigma} = 15.74 \mu\text{rad.}$$

The sample standard deviation is given by

$$s = \left[\frac{\sum_{i=1}^n (\sigma_i - \bar{\sigma})^2}{n-1} \right]^{\frac{1}{2}} = \left[\frac{\sum_{i=1}^n \sigma_i^2 - \frac{1}{n} \left(\sum_{i=1}^n \sigma_i \right)^2}{n-1} \right]^{\frac{1}{2}} \quad (3)$$

and

$$s = 3.51 \mu\text{rad.}$$

Normal distribution is characterized by a skewness of 0 and a kurtosis of 3 where

$$\text{Skewness} = \alpha_3 = \frac{\mu_3}{s^3} = \frac{\frac{1}{n} \sum_{i=1}^n (\sigma_i - \bar{\sigma})^3}{s^3} \quad (4)$$

$$\text{Kurtosis} = \alpha_4 = \frac{\mu_4}{s^4} = \frac{\frac{1}{n} \sum_{i=1}^n (\sigma_i - \bar{\sigma})^4}{s^4} \quad (5)$$

The distribution of combined horizontal and vertical data has

$$\alpha_3 = 0.15$$

and

$$\alpha_4 = 3.12$$

and therefore closely approximated normal or Gaussian distribution. A normal distribution curve was fitted to the observed data after a method by Hald [2] (Fig. 20).

Since the sample mean and the sample standard deviation are not the true mean and true standard deviation, a confidence level must be placed on the probability factor. Using the tables of Bowker and Lieberman [3] and data of Figure 20, we claim that for any random sample the probability is 99 percent that the $\bar{\sigma} + 3s$ level (rms limit) will be less than or equal to 26 μrad . A confidence level of 0.97 is placed on this probability.

A probability prediction of the limit of peak value is afforded by the composite amplitude density distribution found in the following manner. The raw data (Fig. 6), when processed as described on page 5, produce the individual amplitude density plots for the individual observations. Examples of individual amplitude densities are shown in Figure 21.

The processing method shows the mean $\mu_i = 0$ for individual amplitude density distribution, since a symmetrical distribution is produced only for a mean of zero.

From the fact that mean $\mu_i = 0$, treating each individual run as a set and using the standard deviations from Table I, a composite amplitude density distribution is found using a method of Kenny [4].

The equation for combination of n sets into a single set is:

$$N \sigma_{\text{comp}}^2 = \sum_{i=1}^n k_i \sigma_i^2 + \sum_{i=1}^n k_i d_i^2 \quad (6)$$

where

$$N = \sum_{i=1}^n k_i$$

$$d_i = \mu_i - \mu$$

and μ_i = mean of individual amplitude density

μ = mean of composite amplitude density.

For application here

$$d_i = 0 \text{ since } \mu_i = \mu = 0$$

$k_i = k = 1$ since we treat each run as a set of equal weight, i.e., each run represents an equal amount of sampling

$$N = \sum_{i=1}^n k_i = nk = n = \text{number of individual sets or runs.}$$

Equation 6 becomes

$$\sigma_{\text{comp}} = \left[\frac{1}{n} \sum_{i=1}^n \sigma_i^2 \right]^{\frac{1}{2}} \quad (7)$$

where σ_i is found from Table I.

σ_{comp} = composite standard deviation for the combined sets.

Using equation 7 and summing over the entire range of n sets, the composite standard deviation is

$$\sigma_{\text{comp}} = 16.1 \mu\text{rad}$$

This composite σ provides the composite amplitude density distribution (Fig. 22). From this we can state with a confidence of 0.97 that, for any random sample, 99 percent of the total time the amplitude of the angular deviation will be less than or equal to 48.3 μrad . Thus, for any random instant, chances are 1 in 100 for the occurrence of an amplitude greater than 48.3 μrad .

Case II. - Raw data (Fig. 23), processed in the same manner as Case I, produce amplitude (V rms) versus frequency of fluctuation curves normalized to a 1 Hz bandwidth (Figs. 24 through 26). These amplitude-versus-frequency curves, unlike those of Case I, did not naturally fall into different groupings. The measured horizontal and vertical deviations were considered independent observations and analyzed collectively in the selected region of 0 to 15 Hz. The rms mean for horizontal deviations was 8.5 μrad and that for the vertical was 9.8 μrad . Neither was consistently larger than the other.

The individual σ_i (rms) for 0 to 15 Hz for each of the 52 runs is tabulated in order of increasing magnitude (Table II). From the σ_i (rms) values of Table II, a frequency histogram was prepared showing the distribution of combined horizontal and vertical measurements (Fig. 27). The total of 52 observations constitutes one sample. The sample mean and the sample standard deviation of this distribution were calculated using equations (2) and (3).

$$\text{Sample mean} = \sigma = \sum_{i=1}^n \frac{\sigma_i}{n} = 9.19 \mu\text{rad}$$

$$\begin{aligned} \text{Sample standard deviation} = s &= \left[\frac{\sum_{i=1}^n \sigma_i^2 - \frac{(\sum_{i=1}^n \sigma_i)^2}{n}}{n-1} \right]^{\frac{1}{2}} \\ &= 2.50 \mu\text{rad} \end{aligned}$$

Skewness and kurtosis for this distribution were respectively

$$\alpha_3 = 0.35$$

$$\alpha_4 = 2.01$$

Therefore, the distribution of Case II is not as nearly Gaussian as was that for Case I. The atmospheric process controlling optical angular deviations is known to be Gaussian. The departure of Case II distribution from Gaussian is believed to be caused by the operation of heavy construction equipment near the experimental site. Evidence of this is shown in Figures 24 through 26 by the

large amplitude spike at approximately 12 Hz. A normal distribution curve was fitted to the observed data after a method of Hald [2] (Fig. 28).

From the data of Figure 28 and using the tables of Bowker and Lieberman [3], the probability is 99 percent that, for any random sample, the $\bar{\sigma} + 3 s$ level (rms limit) will be less than or equal to $17 \mu\text{rad}$. A confidence level of 0.97 is placed on this probability.

A probability prediction of the limit of peak value is afforded by the composite amplitude density distribution of Case II, found in the following manner. As in Case I, the processed data produce the individual amplitude densities (page 5). Examples of typical individual amplitude densities are shown in Figure 29.

The processing method shows the mean $\mu_i = 0$ for individual amplitude density distribution. Using the standard deviation values of Table II and equation 7, the composite standard deviation of the combined sets is

$$\sigma_{\text{comp}} = \left[\frac{1}{n} \sum_{i=1}^n \sigma_i^2 \right]^{\frac{1}{2}} = 9.52 \mu\text{rad}.$$

This composite σ provides the composite amplitude density plot (Fig. 30). From this we can state with a confidence of 0.97 that, for any random sample, 99 percent of the total time the amplitude of the angular deviation will be less than or equal to $28.6 \mu\text{rad}$. Thus, for any random instant, chances are 1 in 100 for the occurrence of an amplitude greater than $28.6 \mu\text{rad}$.

Data Tabulation

Case I. - Table III gives the date and time of the observation periods in chronological order and rms values of the 0 to 15 Hz range for each observation. The curve notation H or V denotes horizontal and vertical observations; A, B, C, D, or E denotes grouping (page 6). The atmospheric parameters, temperature, pressure, humidity, and winds are presented for the transmitting and receiving stations; synoptic weather conditions are presented for each day.

Case II. - Table IV gives the date and time of the observation periods in chronological order. The curve notation H or V denotes horizontal and vertical observations. The atmospheric parameters, temperature, pressure, humidity,

and winds are presented for the receiving station only; it was impractical to take these data at the transmitting site of Case II. Synoptic weather conditions are again presented for each day.

CONCLUSIONS

Data on atmospheric angular deviations were recorded for approximately six months and over two different path lengths. Data from each case were analyzed for the selected frequency range of 0 to 15 Hz. Basic results of the two path length measurements are tabulated as follows.

	<u>Case I</u>	<u>Case II</u>
Path length.	3200 m $\pm 1\%$	165 m $\pm 1\%$
Rms mean 0 to 15 Hz	15.74 μ rad	9.19 μ rad
Limiting rms 0 to 15 Hz	26 μ rad	17 μ rad
Limiting peak 0 to 15 Hz	48.3 μ rad	28.6 μ rad
Rms 0 - 150 Hz/rms 0 to 15 Hz	2	1.5

Correlation of measured angular deviation to atmospheric data was not attempted because of lack of an atmospheric model. Data on frequency of fluctuation up to 150 Hz were recorded to be used in the formulation of an atmospheric model in a later report. Atmospheric data and corresponding measured angular deviations for 0 to 15 Hz have been presented in Tables III and IV.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama, February 16, 1966.

TABLE I

<u>Curve</u>	<u>0 to 15 Hz rms μrad</u>		<u>Curve</u>	<u>0 to 15 Hz rms μrad</u>
BH6	8.4		BV14	15.5
BH11	9.1		BH2	15.6
BV5	9.2		DV2	15.7
BH7	10.1		DH1	15.8
BH9	10.3		DH6	16.1
BV3	11.9		AH2	16.2
BV9	12.0		EH2	16.4
BH4	12.5		CH2	16.8
AH4	12.6		EV1	16.8
BH12	12.7		AH1	17.0
CH3	13.0		BV8	17.1
AH5	13.2		CV3	17.1
BV13	13.2		DH2	17.1
BV11	13.3		EV3	17.3
BV4	13.4		EH1	17.7
BH5	13.4		EV2	18.4
BH8	13.6		DH7	19.0
BH3	13.8		CV1	19.4
AV1	14.2		DH4	19.6
BV2	14.4		CV4	19.9
BH10	14.4		DH5	20.9
BV6	14.8		CV2	21.0
DV1	14.8		DV3	21.0
BV10	15.0		CH1	21.9
BV1	15.2		DH3	21.9
BV7	15.2		DV4	21.9
BV12	15.5		CH4	22.0
			CV5	22.0

Explanation of curve notation:

A, B, C, D, E curve grouping (see page 6)
H and V horizontal or vertical observation

TABLE II

<u>Curve</u>	<u>0 to 15 Hz rms μrad</u>	<u>Curve</u>	<u>0 to 15 Hz rms μrad</u>
V5	5.2	V26	8.8
H16	5.4	V18	8.9
H18	5.5	H10	9.4
H8	5.9	H21	9.5
H22	6.0	V21	9.8
H5	6.1	H25	10.0
H24	6.1	H1	10.1
V15	6.4	H3	10.1
H17	6.4	V25	10.2
H20	6.4	H23	10.4
V24	6.4	V10	10.8
H9	6.5	V13	10.8
V16	6.5	V14	10.8
V20	6.6	V3	11.0
V22	7.2	H7	11.2
H26	7.5	V19	11.5
V9	7.7	V1	11.8
H15	7.9	V4	11.8
H14	8.1	H13	12.0
V6	8.2	V17	12.0
H6	8.3	V8	12.6
H19	8.3	H11	13.2
V23	8.3	V12	13.6
H2	8.4	H12	14.0
V2	8.4	V7	14.2
H4	8.4	V11	14.6

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III

Date	Time	Curve #	rms (0-15 Hz) μ rad	Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W _s m/s	W _{dir} ¹	Synoptic Conditions ²
27 Jan 65	13:18	AH1	17.0	T + 4.5	35.0	738.6	3.0	270°	Huntsville was on the east side of a high pressure centered in Texas. Light northwesterly surface winds, southwesterly at 375 mm Hg. Maximum temperatures in low 40's. Minimum temperatures in mid 20's. Fair skies. Nearest frontal system was a cold front off South Florida.
				R + 4.0	35.0	749.8	3.0	300°	
27 Jan 65	13:33	BH1	15.8	T + 5.0	35.0	738.4	3.0	270°	
				R + 4.0	34.5	749.8	3.0	280°	
27 Jan 65	13:45	AH2	16.2	T + 5.5	35.0	738.1	3.0	270°	
				R + 4.5	34.0	749.8	3.0	300°	
27 Jan 65	13:53	DV1	14.8	T + 5.5	35.0	737.9	3.5	270°	
				R + 4.5	34.0	749.8	3.0	300°	
27 Jan 65	14:00	DV2	15.7	T + 5.5	34.0	737.9	2.5	285°	
				R + 5.0	34.0	750.1	4.0	300°	
27 Jan 65	14:10	BV1	15.2	T + 5.5	34.0	737.6	4.0	280°	
				R + 5.0	33.0	750.1	3.5	275°	

¹True North = 360°

²These conditions were reported by Mr. H. D. Bagley, Physical Science Laboratory, Aerophysics Branch, Army Missile Command. Temperatures stated are given in Fahrenheit.

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W _s m/s	W _{dir}	Synoptic Conditions
3 Feb 65	10:36	CV1	19.4	T	- 3.0	43.0	745.2	3.0	30°	Huntsville was near the center of a high pressure ridge extending from South Georgia, northwest into Montana. Calm surface winds. Strong northwesterly winds at 375 mm Hg. Maximum temperatures in upper 30's. Minimum temperatures near 10. Few high cirrus clouds. No fronts in the area.
				R	- 3.0	43.0	749.6	2.0	30°	
3 Feb 65	10:43	BH4	12.5	T	- 2.5	44.0	745.2	3.0	30°	
				R	- 3.0	45.0	749.6	2.0	30°	
3 Feb 65	12:32	BH2	15.6	T	- 1.5	42.0	744.7	3.0	30°	
				R	- 1.0	42.0	750.1	1.5	60°	
3 Feb 65	12:40	DV3	21.0	T	- 1.0	42.0	744.7	1.5	30°	
				R	- 0.5	41.0	750.1	1.5	60°	
4 Feb 65	10:24	BH3	13.8	T	+ 1.5	43.0	746.8	2.5	40°	Huntsville was on south edge of a high pressure centered in Kentucky. Light easterly surface winds. Northwesterly at 375 mm Hg. Maximum temperatures in mid 40's. Minimum temperatures near 20. Few high cirrus clouds. No fronts in the area.
				R	+ 2.0	41.0	751.3	2.5	240°	
4 Feb 65	10:32	DV2	14.4	T	+ 1.5	43.0	746.8	2.5	40°	
				R	+ 2.0	41.0	751.3	2.5	240°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad	Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
4 Feb 65	12:35	DH2	17.1	T + 3.5	39.0	745.5	2.0	30°	
				R + 4.0	38.0	752.3	1.5	240°	
4 Feb 65	12:46	EV1	16.8	T + 4.0	38.0	745.0	1.0	20°	
				R + 4.5	37.0	752.3	1.0	230°	
4 Feb 65	13:23	DH3	21.9	T + 4.5	35.0	744.7	2.0	40°	
				R + 4.5	36.0	752.6	1.5	240°	
4 Feb 65	13:31	EV2	18.4	T + 4.5	36.0	744.7	2.0	40°	
				R + 4.5	36.0	752.6	1.5	240°	
5 Feb 65	12:03	EH2	16.4	T + 8.0	30.0	744.2	3.0	150°	Huntsville was near center of a high pressure ridge extending from Cape Hatteras to Texas. Light south surface winds. Southwesterly at 375 mm Hg. Moisture increasing. Strato-cumulus and altocumulus clouds. Maximum temperatures in low 50's. Minimum temperatures near 20.
				R + 8.0	35.0	754.6	2.5	300°	
5 Feb 65	12:09	BV3	11.9	T + 8.0	30.0	744.2	3.0	160°	
				R + 8.5	35.0	754.6	2.0	320°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
5 Feb 65	12:29	EH1	17.7	T	+ 8.5	29.0	740.9	2.0	160°	Huntsville was in a warm air mass with light rain in the area. Cold front across Northwest Mississippi moving Southeast toward Huntsville. Surface winds, Southeast. Maximum temperatures near 70. Minimum temperatures near 50.
				R	+ 9.5	35.0	754.9	1.5	360°	
5 Feb 65	12:36	BV4	13.4	T	+ 8.5	29.0	740.9	2.0	170°	
				R	+ 9.5	35.0	754.9	1.5	330°	
8 Feb 65	10:30	CH1	21.9	T	+ 16.0	72.0	738.4	3.0	310°	
				R	+ 18.0	62.0	753.9	0.5	180°	
8 Feb 65	10:44	CV2	21.0	T	+ 16.5	68.0	738.4	0.5	330°	
				R	+ 18.0	65.0	754.4	0.5	270°	
8 Feb 65	11:45	CH2	16.8	T	+ 16.5	70.0	737.9	1.0	360°	
				R	+ 18.0	65.0	753.9	0.5	250°	
8 Feb 65	11:52	BV5	9.2	T	+ 16.5	68.0	737.9	0.5	360°	
				R	+ 17.0	65.0	753.9	1.0	210°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad	Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
15 Feb 65	9:30	CH3	13.0	T	---	---	---	1.0	90°
				R	+ 4.0	48.0	747.8	1.0	100°
15 Feb 65	9:45	CV3	17.1	T	---	---	---	1.0	90°
				R	+ 4.5	44.0	747.8	0.5	100°
15 Feb 65	10:02	DH4	19.6	T	---	---	---	1.0	90°
				R	+ 5.0	45.0	747.8	1.5	120°
15 Feb 65	10:10	CV4	19.9	T	---	---	---	1.5	120°
				R	+ 5.0	45.0	747.8	1.5	150°
15 Feb 65	12:21	DH5	20.9	T	---	---	---	2.0	90°
				R	+ 8.5	32.0	748.8	1.0	120°
15 Feb 65	12:35	DV4	21.9	T	---	---	---	1.5	90°
				R	+ 9.0	31.0	749.0	2.5	90°

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press: mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
15 Feb 65	12:43	DH6	16.1	T	---	---	---	2.5	90°	A cold front was across North Alabama in the vicinity of Huntsville. Wind shifted to northerly during the afternoon. Maximum temperatures near 60. Minimum temperatures near 30. Clearing skies.
				R	+ 9.5	31.0	749.0	1.5	90°	
19 Feb 65	9:31	BH5	13.4	T	+ 10.0	46.0	735.1	3.0	20°	
				R	+ 9.5	44.0	752.1	3.5	10°	
19 Feb 65	9:39	BV6	14.8	T	+ 10.0	45.0	735.1	2.0	345°	
				R	+ 10.0	42.0	752.1	3.0	360°	
19 Feb 65	9:47	BH9	10.3	T	+ 10.5	42.0	735.1	4.0	10°	
				R	+ 10.0	40.0	752.1	3.5	360°	
19 Feb 65	9:53	BV7	15.2	T	+ 10.5	42.0	735.1	3.0	10°	
				R	+ 10.0	40.0	752.1	3.5	340°	
19 Feb 65	12:43	BH6	8.4	T	+ 12.0	32.0	735.1	3.0	20°	
				R	+ 12.0	35.0	751.8	4.0	360°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. in Hg.	W_s m/s	W_{dir}	Synoptic Conditions
19 Feb 65	12:49	BV8	17.1	T	+ 12.0	32.5	734.8	2.5	360°	The remainder of a dissipating stationary front was in Northern Mississippi with a stationary front and low pressure in the Gulf. South-easterly wind flow over North Alabama. Broken stratocumulus and cirrus clouds. Strong southwesterly wind flow at 375 mm Hg. Maximum temperatures near 60. Minimum temperatures near 25.
				R	+ 12.0	35.0	751.8	3.5	360°	
23 Feb 65	9:35	BH7	10.1	T	+ 6.5	26.0	733.6	3.0	120°	
				R	+ 6.5	32.0	749.3	3.5	330°	
23 Feb 65	9:47	BV9	12.0	T	+ 6.5	26.0	733.6	3.5	120°	
				R	+ 7.0	32.0	749.3	3.5	330°	
23 Feb 65	10:08	AH4	12.6	T	+ 8.0	26.0	733.3	4.0	130°	
				R	+ 8.0	32.0	749.3	3.0	310°	
23 Feb 65	10:19	BV10	15.0	T	+ 8.0	26.0	733.3	4.0	140°	
				R	+ 9.0	30.0	749.3	2.5	330°	
23 Feb 65	13:59	AH5	13.2	T	+ 14.0	15.0	730.8	4.0	150°	
				R	+ 13.5	19.0	747.5	3.0	320°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W _s m/s	W _{dir}	Synoptic Conditions
23 Feb 65	14:06	AV1	14.2	T	+ 13.5	15.0	730.5	5.0	150°	
				R	+ 13.5	19.0	747.5	3.5	330°	
26 Feb 65	10:20	BH8	13.6	T	+ 3.5	46.0	739.6	3.0	280°	Huntsville was under the influence of a high pressure ridge with its center in the Gulf of Mexico. Weak northwest wind flow at the surface. Strong northwest at 375 mm Hg. Maximum temperatures near 40. Minimums near 20. Few high cirrus clouds.
				R	+ 3.0	46.0	751.1	3.0	290°	
26 Feb 65	10:36	BV11	13.3	T	+ 3.5	43.0	737.1	3.5	280°	
				R	+ 3.5	46.0	751.3	4.0	290°	
10 Mar 65	10:31	BH10	14.4	T	+ 6.0	33.0	735.1	3.0	330°	A fast moving cold front passed eastward through Huntsville during the evening of 9 March. This brought an end to light showers which had given an average of .02 inch of rain to North Alabama. The day of 10 March was clearing and averaged about 25 degrees cooler than the previous day. Highest temperatures in North Alabama were about 50 degrees. Lowest temperatures were
				R	+ 5.5	43.0	749.0	3.0	130°	
10 Mar 65	10:38	BV12	15.5	T	+ 6.5	33.0	735.1	2.0	330°	
				R	+ 5.5	42.0	749.0	2.0	150°	
10 Mar 65	12:34	BH11	9.1	T	+ 8.0	31.0	735.1	1.5	300°	(Continued)
				R	+ 7.5	36.0	750.3	3.5	120°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad	Temp. Deg. C.	Rel. Humd., %	Press. mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
10 Mar 65	12:42	BV13	13.2	T + 8.0	31.0	735.1	3.0	300°	near 35 degrees. Surface winds were light northerly. Winds aloft were westerly 75 to 85 mph at the 375 mm Hg. level.
				R + 8.0	35.0	750.3	3.0	150°	
11 Mar 65	8:40	CH4	22.0	T + 10.0	35.0	734.1	0.5	300°	North Alabama was in a high pressure ridge which extended southward from Quebec to the Gulf of Mexico. Skies were mostly clear, and with abundant sunshine, temperatures were moderating rapidly. Highest temperatures were near 65 degrees after an overnight low of near 30 degrees. Surface winds were light and variable. Winds at the 375 mm Hg. level were WSW 70 to 80 mph.
				R + 9.5	37.0	751.8	1.0	270°	
11 Mar 65	8:47	CV5	22.0	T + 10.0	35.0	734.1	0.5	300°	
				R + 10.0	36.0	751.8	1.0	270°	
11 Mar 65	12:15	DH7	19.0	T + 15.0	33.0	734.6	1.0	330°	
				R + 15.0	33.0	752.6	1.0	170°	
11 Mar 65	12:22	BV14	15.5	T + 15.5	32.5	734.6	1.0	330°	
				R + 15.5	33.0	752.6	1.5	170°	
19 Mar 65	13:24	BH12	12.7	T + 8.5	45.0	731.3	3.0	330°	A low pressure disturbance was moving eastward along the Gulf Coast. A wave extended northward (continued)
				R + 8.5	46.0	750.3	4.0	360°	

All 5 Min. Runs

T = Transmission Site

R = Receiving Site

TABLE III (Concluded)

[illegible]

All 5 Min. Runs

R = Receiving Site

TABLE IV

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W_s m/s	W_{dir}^1	Synoptic Conditions ²
4 May 65	13:08	H1	10.1	R	+ 26.5	36.0	753.9	1.5	240°	The normal spring season extension of the Bermuda high was causing high pressure over North Alabama. Light southerly surface winds were bringing warm MT air into the area. Skies were clear to partly cloudy. Highest temperatures were near 85 degrees, lowest near 55. Winds at the 375 mm Hg. level were light westerly 5 to 10 mph.
4 May 65	13:14	V1	11.8	R	+ 26.5	36.0	753.9	2.0	240°	
4 May 65	13:57	H2	8.4	R	+ 26.5	35.0	753.4	1.0	270°	
4 May 65	14:03	V2	8.4	R	+ 26.5	35.0	753.4	1.5	270°	
5 May 65	8:30	H3	10.1	R	+ 21.0	51.0	753.4	1.5	260°	A high pressure ridge extended from the Atlantic high across Alabama and the Southeastern United States. Circulation around this high caused light southerly surface winds over North Alabama. Skies were clear during most of the day. Highest temperatures were near 85 degrees. Lowest near 60. Winds aloft at the 375 mm Hg. (19,100 ft.) level were north-westerly near 15 mph.
5 May 65	8:36	V3	11.0	R	+ 21.0	51.0	753.9	2.0	270°	
5 May 65	11:07	H4	8.4	R	+ 24.5	40.0	753.4	2.5	230°	
5 May 65	11:13	V4	11.8	R	+ 25.0	40.0	753.1	2.0	210°	
5 May 65	12:57	H5	6.1	R	+ 24.5	40.0	753.1	3.5	250°	
5 May 65	13:03	V5	5.2	R	+ 25.0	39.0	752.3	2.0	250°	

¹True North = 360°²These conditions were reported by Mr. H. D. Bagley, Physical Science Laboratory, Aerophysics Branch, Army Missile Command. Temperatures stated are given in Fahrenheit.

All 5 Min. Runs

R = Receiving Site

TABLE IV (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W _s m/s	W _{dir}	Synoptic Conditions
6 May 65	7:59	H6	8.3	R	+ 20.5	56.0	752.6	1.0	20°	An extension of the Bermuda high pressure ridge was still across the area, but beginning to weaken. A few cirrus clouds started moving in from the west. Highest temperatures near 85, lowest near 55. Surface winds were light southerly. Winds at 375 mm Hg. were south-westerly 10 to 20 mph.
6 May 65	8:07	V6	8.2	R	+ 20.5	56.0	752.6	0.0	360°	
6 May 65	10:35	H7	11.2	R	+ 25.0	46.0	752.6	1.0	360°	
6 May 65	10:41	V7	14.2	R	+ 25.0	46.0	752.6	3.0	75°	
6 May 65	12:47	H8	5.9	R	+ 27.0	43.0	751.8	1.5	60°	
6 May 65	12:54	V8	12.6	R	+ 26.5	43.0	751.8	1.0	30°	
6 May 65	14:31	H9	6.5	R	+ 27.0	44.0	751.3	1.5	60°	A modified continental polar air mass with associated high pressure was centered over North Alabama and North Mississippi. In this dry air skies were mostly clear and surface winds were light and variable. Highest temperatures were near 85 degrees, lowest near 50. (continued)
6 May 65	14:38	V9	7.7	R	+ 27.0	44.0	751.3	1.0	60°	
13 May 65	8:04	H10	9.4	R	+ 18.5	52.0	751.8	0.0	360°	
13 May 65	8:10	V10	10.8	R	+ 19.0	52.0	751.8	0.0	360°	
13 May 65	10:20	H11	13.2	R	+ 24.0	32.0	751.3	2.0	60°	
13 May 65	10:26	V11	14.6	R	+ 24.5	30.0	751.1	1.0	90°	

All 5 Min. Runs

R = Receiving Site

TABLE IV (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C.	Rel. Humd. %	Press. mm Hg.	W_s m/s	W_{dir}	Synoptic Conditions
13 May 65	12:47	H12	14.0	R	+ 26.0	25.0	749.8	2.5	30°	Winds at the 375 mm Hg. level were northerly at 20 to 30 mph.
13 May 65	12:53	V12	13.6	R	+ 26.0	25.0	749.8	1.5	60°	
13 May 65	14:28	H13	12.0	R	+ 27.0	25.0	748.8	0.5	360°	
13 May 65	14:34	V13	10.8	R	+ 27.5	25.0	748.8	0.0	270°	
24 May 65	8:31	H14	8.1	R	+ 25.0	54.5	754.4	2.0	330°	Weak high pressure was over North Alabama and all the South-eastern U.S. Light southerly circulation and mostly fair skies caused highest temperatures near 90 degrees. Lowest temperatures were near 65. Although scattered showers and thundershowers occurred in the adjacent states, none were over North Alabama. Winds at the 375 mm Hg. level were light westerly 5 to 10 mph.
24 May 65	8:37	V14	10.8	R	+ 25.0	54.5	754.4	2.0	330°	
24 May 65	12:43	H15	7.9	R	+ 29.5	41.0	753.6	2.0	280°	
24 May 65	12:49	V15	6.4	R	+ 29.5	41.0	753.6	1.5	330°	
1 June 65	8:53	H16	5.4	R	+ 25.0	45.0	753.1	2.5	330°	The seasonal semi-permanent position of the Atlantic high centered off the North Carolina coast (continued)
1 June 65	8:58	V16	6.5	R	+ 25.0	45.0	753.1	1.5	350°	
1 June 65	11:59	H17	6.4	R	+ 29.0	33.0	752.3	1.5	70°	

All 5 Min. Runs

R = Receiving Site

TABLE IV (Cont'd)

[illegible]

All 5 Min. Runs

R = Receiving Site

TABLE IV (Cont'd)

Date	Time	Curve #	rms (0-15 Hz) μ rad		Temp. Deg. C	Rel. Humd. %	Press. mm Hg.	W _s m/s	W _{dir}	Synoptic Conditions
8 June 65	8:02	H20	11.5	R	+ 20.0	69.0	753.4	1.5	150°	A weak high pressure ridge extended westward across North Alabama. Circulation around this ridge caused light southerly winds and warm humid weather. Highest temperatures were near 85, lowest near 65. Skies were partly cloudy. At the 375 mm Hg. level, winds were weak northwesterly 5 to 10 mph.
8 June 65	8:08	V20	6.4	R	+ 20.0	68.5	753.4	2.0	140°	
8 June 65	12:24	H21	9.5	R	+ 26.0	50.0	752.3	0.5	180°	
8 June 65	12:30	V21	9.8	R	+ 26.0	49.5	752.1	0.1	150°	
10 June 65	8:23	H22	6.0	R	+ 25.0	63.0	752.3	1.0	315°	Warm and humid MT air was over the area with showers and fairly general rain in the evening. A stationary front was to the north in Kentucky causing ascending motion of the warm air and considerable cloudiness in North Alabama throughout the day. Highest temperatures were in the upper 80s, lowest near 70 degrees. At 375 mm Hg. wind flow was southwesterly 10 to 20 mph.
10 June 65	8:30	V22	7.2	R	+ 25.0	63.0	752.3	0.5	330°	
10 June 65	12:13	H23	10.4	R	+ 28.0	49.0	752.6	1.0	90°	
10 June 65	12:20	V23	8.3	R	+ 28.5	48.5	752.3	1.0	120°	

All 5 Min. Runs

R = Receiving Site

TABLE IV (Concluded)

[illegible]

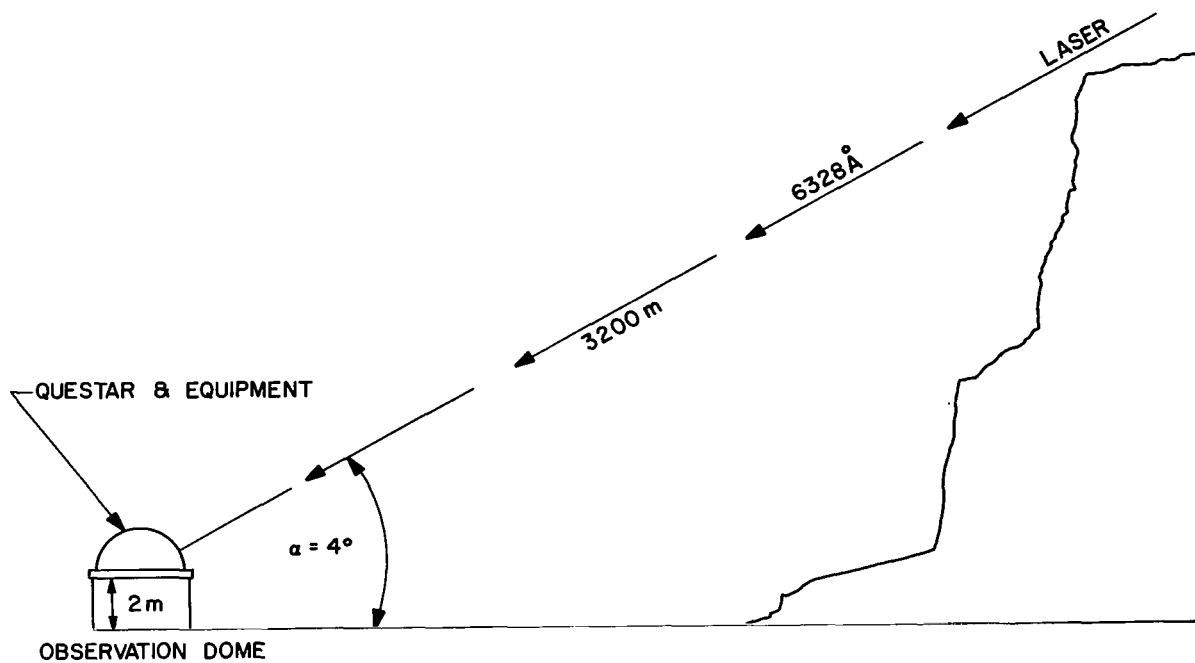


FIGURE 1. EXPERIMENTAL SITE - CASE I.

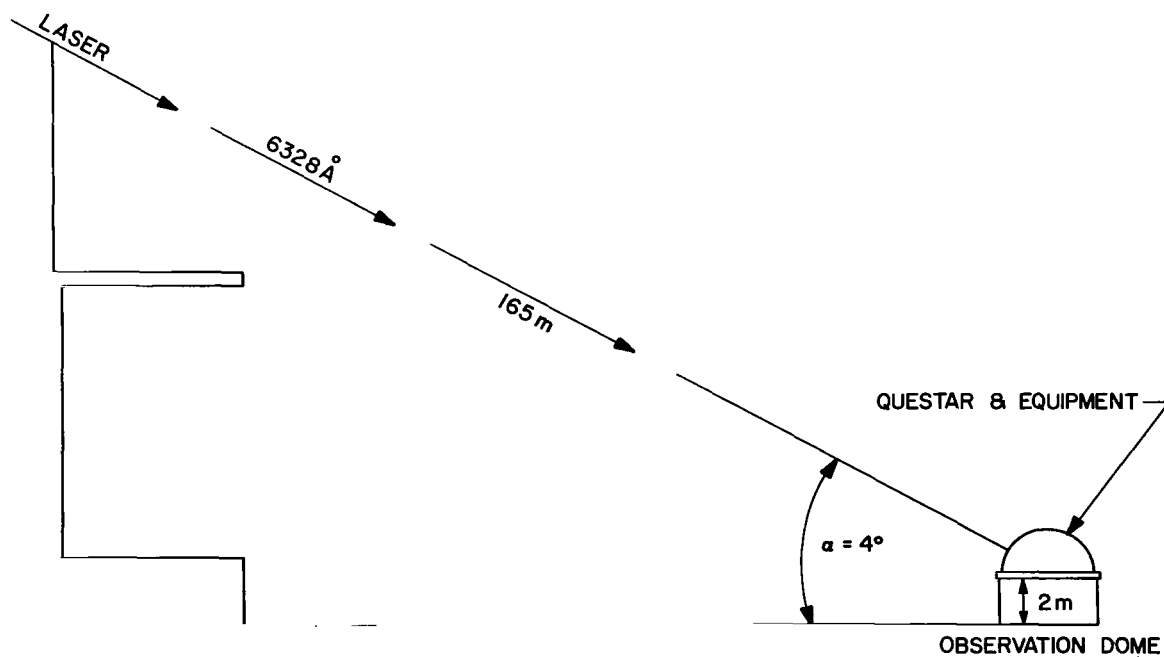


FIGURE 2. EXPERIMENTAL SITE - CASE II.

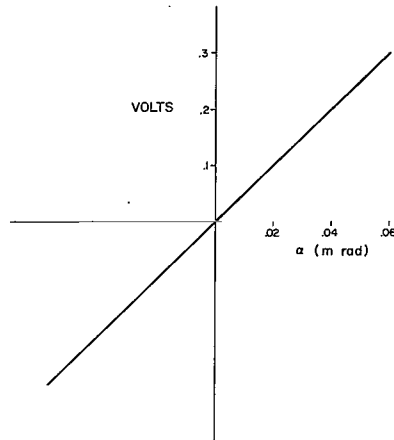


FIGURE 3. TRANSFER CURVE.

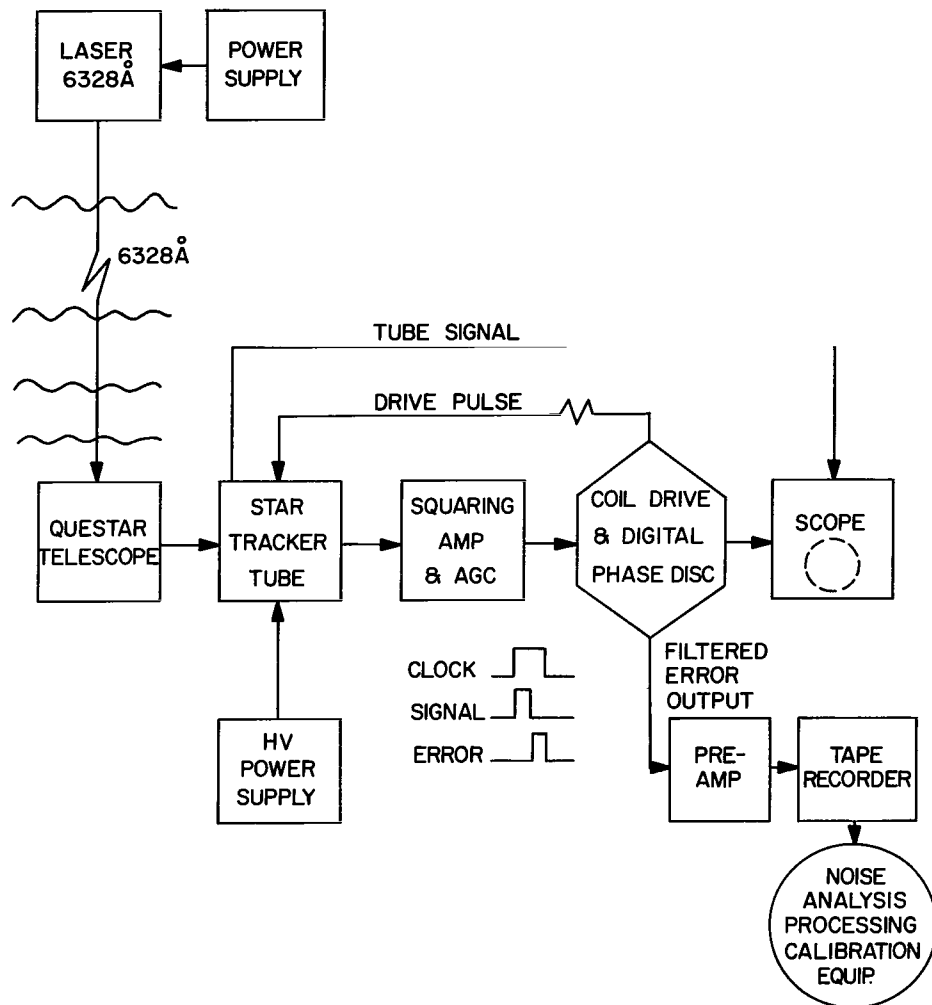


FIGURE 4. BLOCK DIAGRAM OF SIGNAL DETECTION SYSTEM.

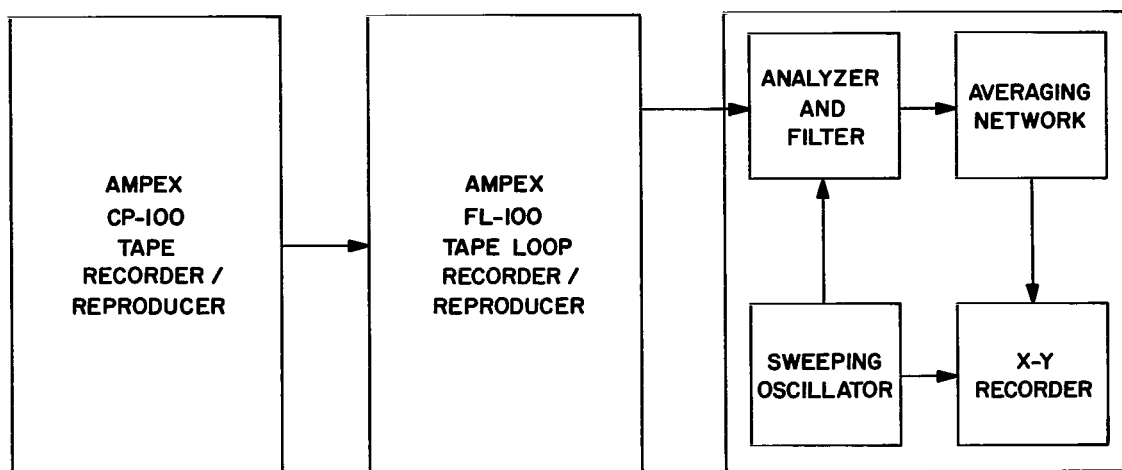


FIGURE 5a. BLOCK DIAGRAM OF SIGNAL PROCESSING EQUIPMENT.

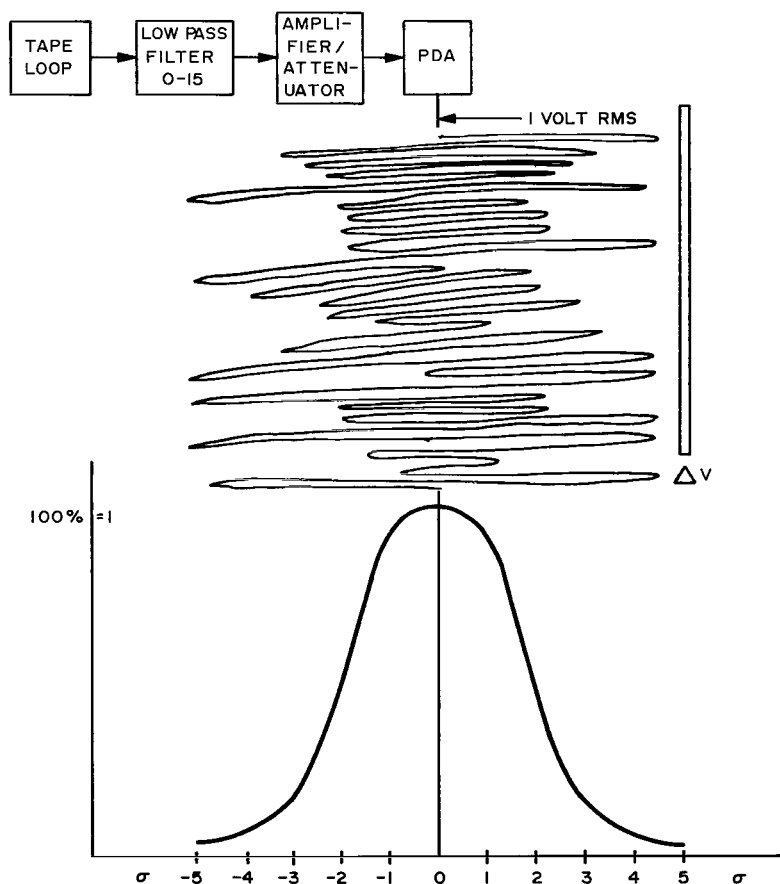


FIGURE 5b. AMPLITUDE DENSITY PROCESS.

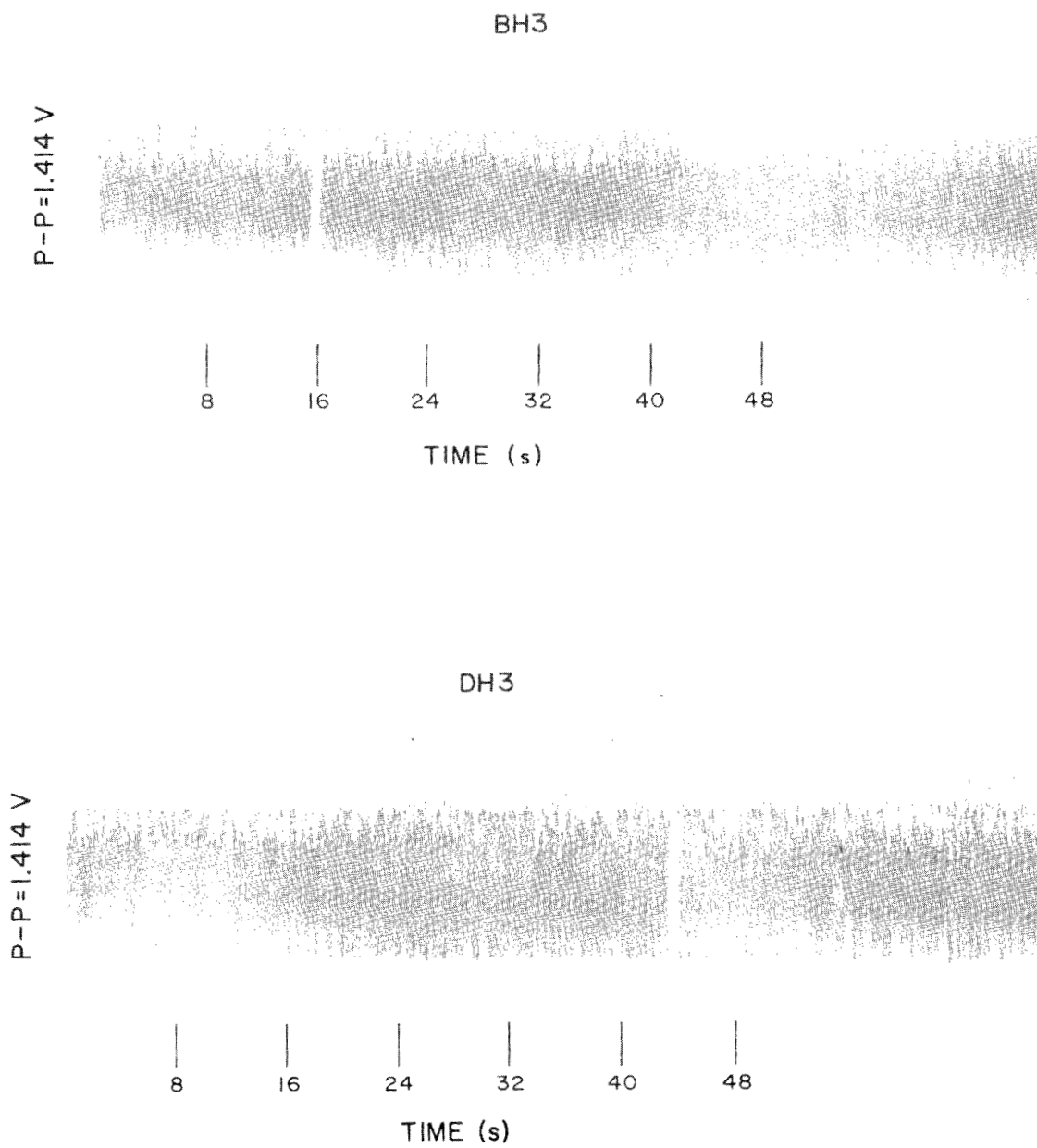
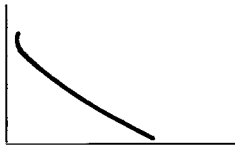


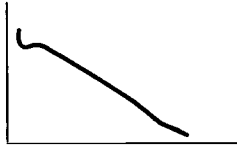
FIGURE 6. RAW DATA OSCILLOGRAPHS - CASE I.

GROUP I

CURVE "A"

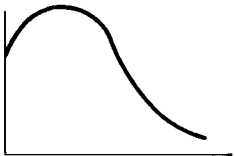


CURVE "B"

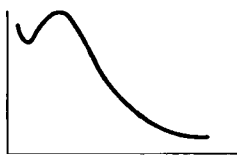


GROUP II

CURVE "C"



CURVE "D"



CURVE "E"

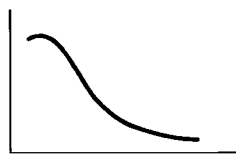


FIGURE 7. SKETCH OF TYPICAL CURVES - CASE I.

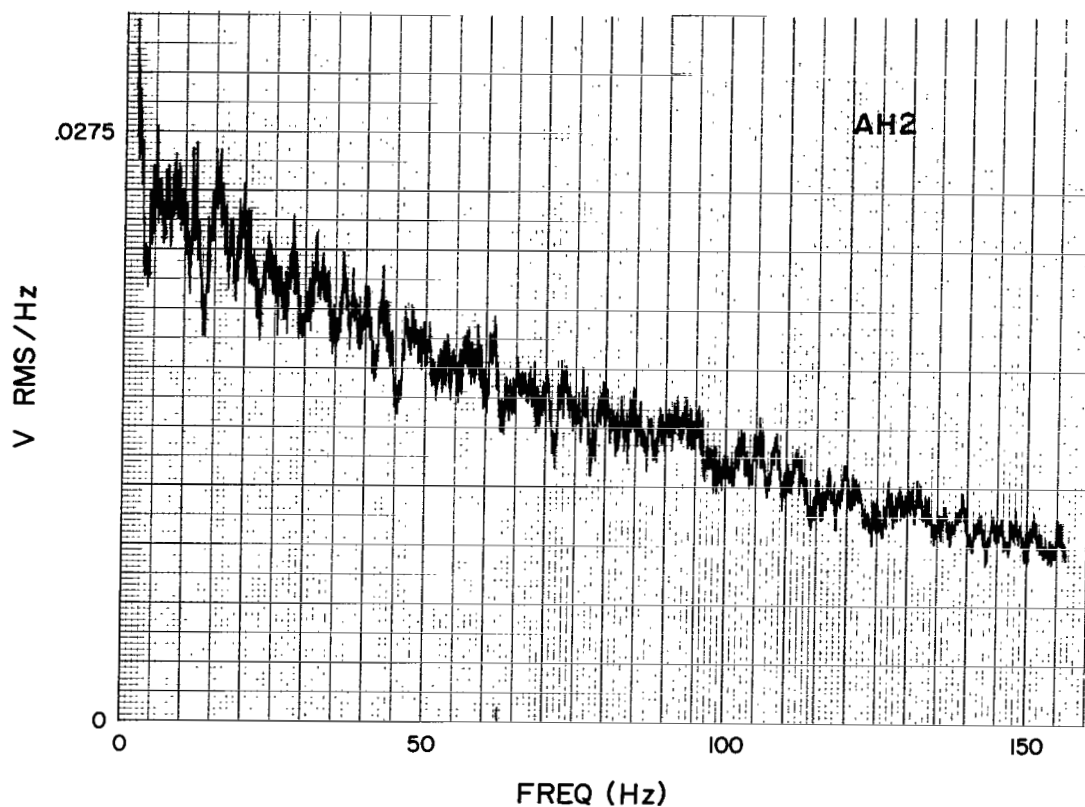


FIGURE 8. EXAMPLE OF TYPICAL CURVE - CASE I.

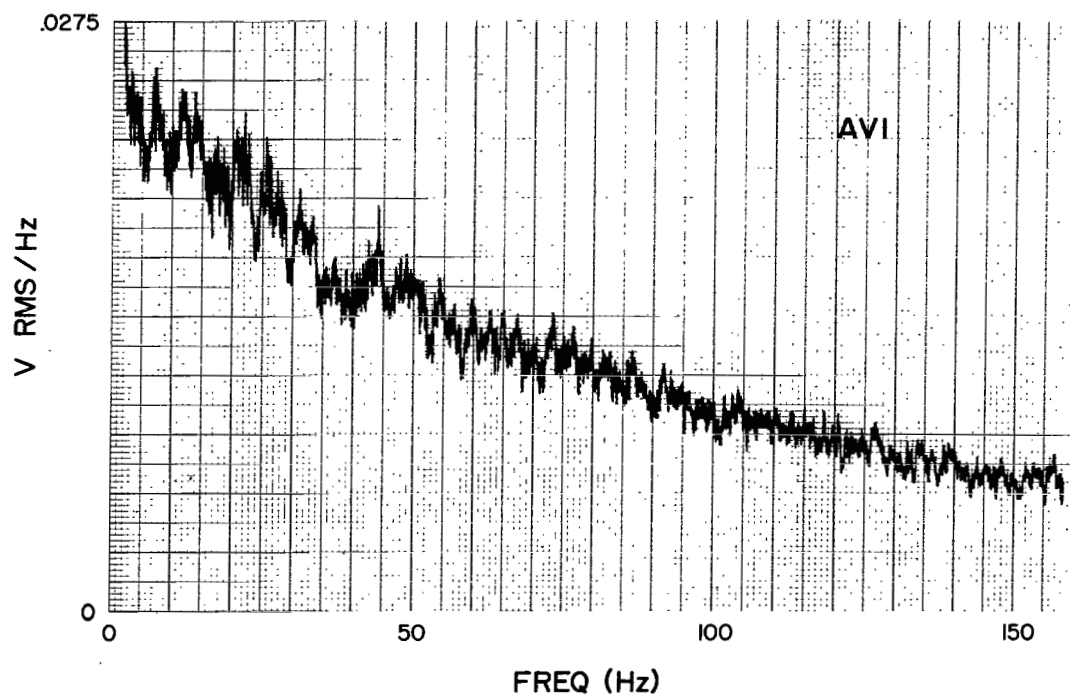


FIGURE 9. EXAMPLE OF TYPICAL CURVE - CASE I.

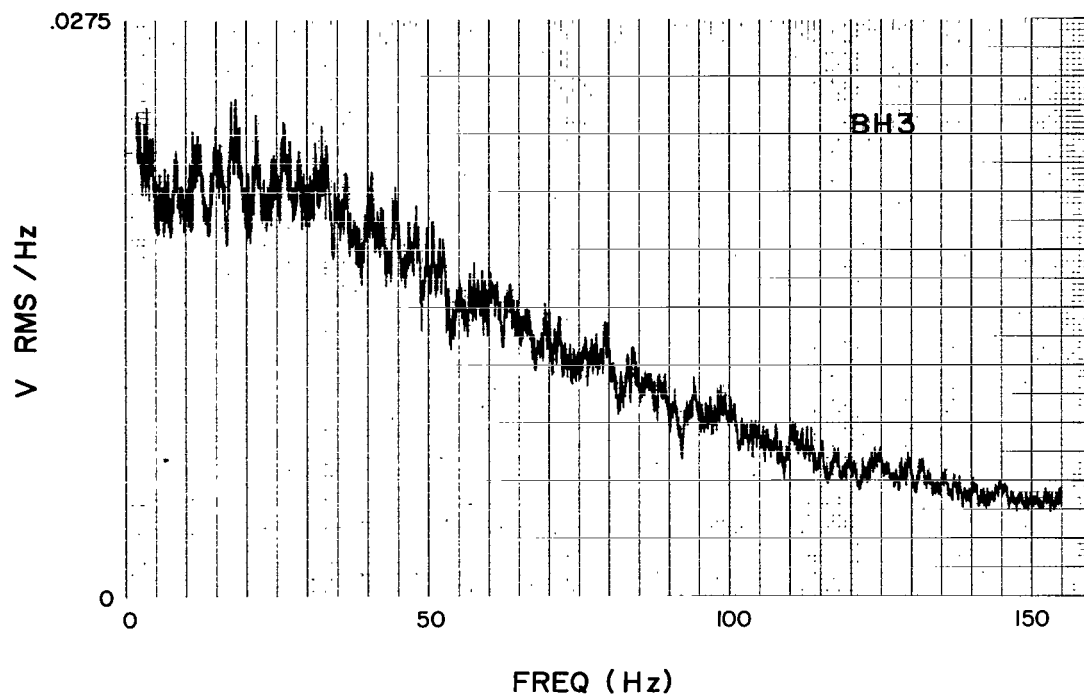


FIGURE 10. EXAMPLE OF TYPICAL CURVE - CASE I.

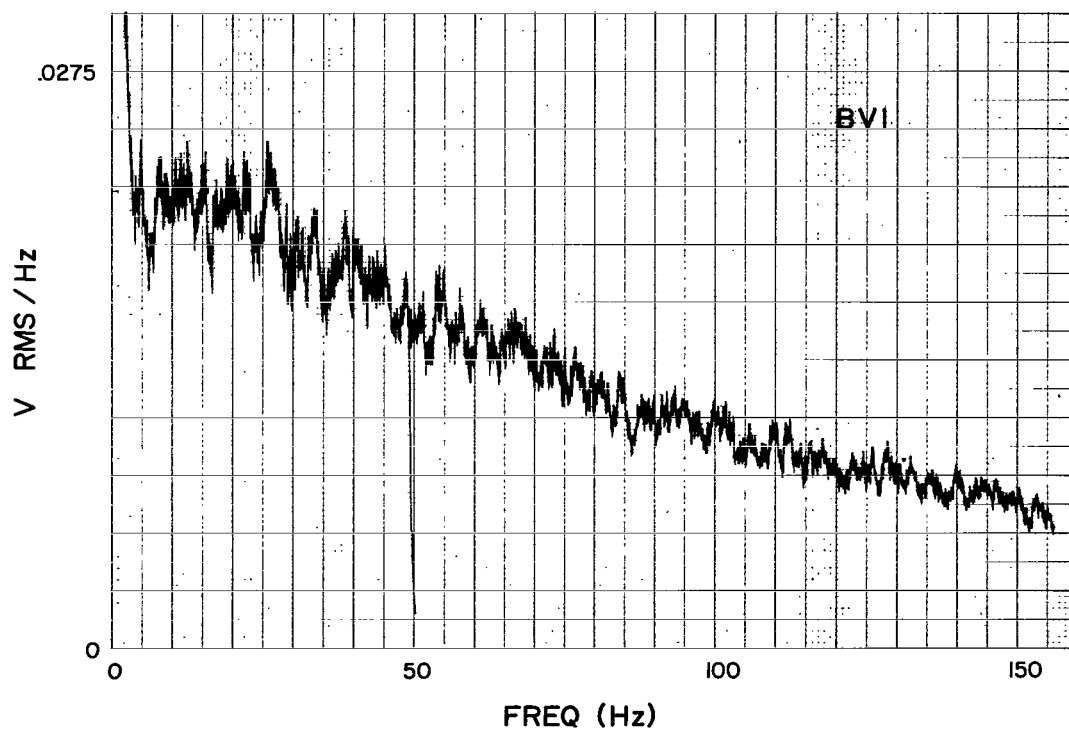


FIGURE 11. EXAMPLE OF TYPICAL CURVE - CASE I.

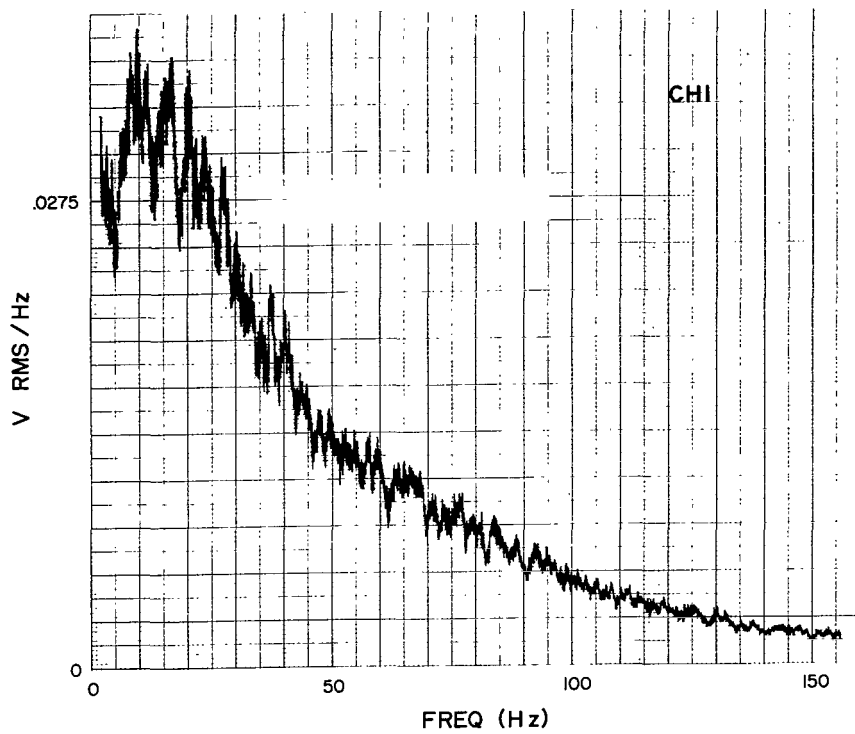


FIGURE 12. EXAMPLE OF TYPICAL CURVE - CASE I.

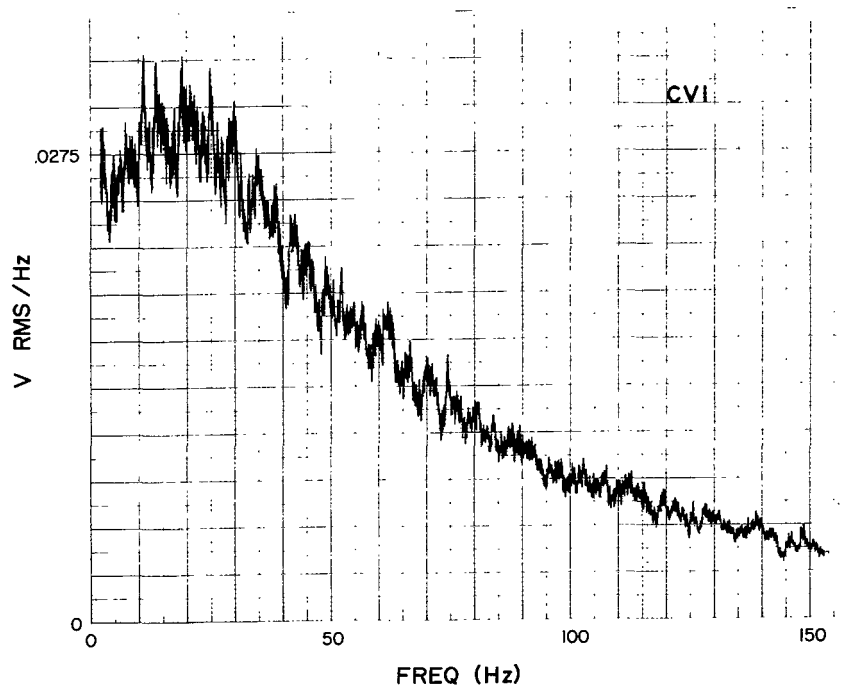


FIGURE 13. EXAMPLE OF TYPICAL CURVE - CASE I.

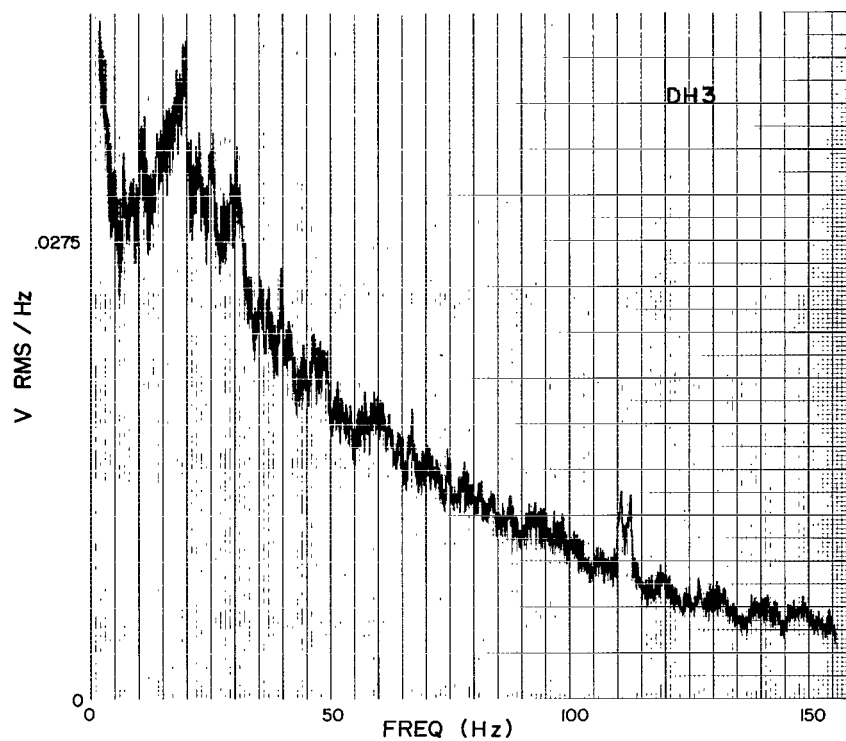


FIGURE 14. EXAMPLE OF TYPICAL CURVE - CASE I.

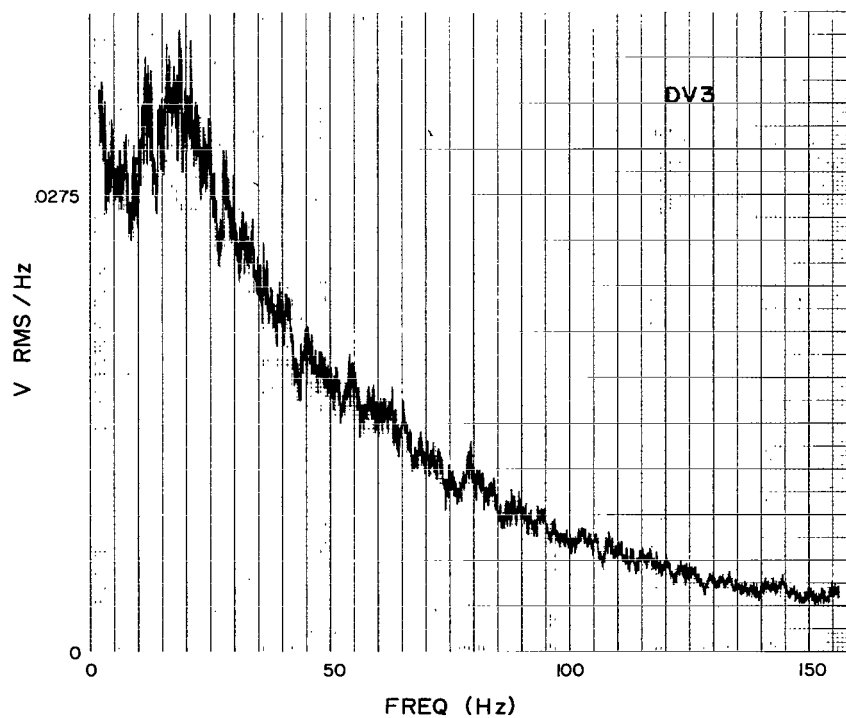


FIGURE 15. EXAMPLE OF TYPICAL CURVE - CASE I.

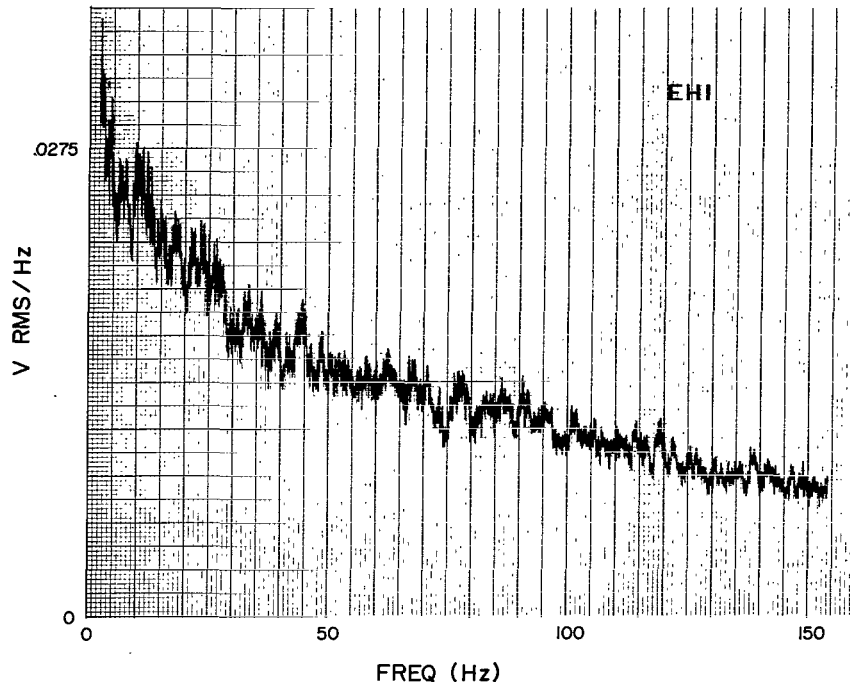


FIGURE 16. EXAMPLE OF TYPICAL CURVE - CASE I.

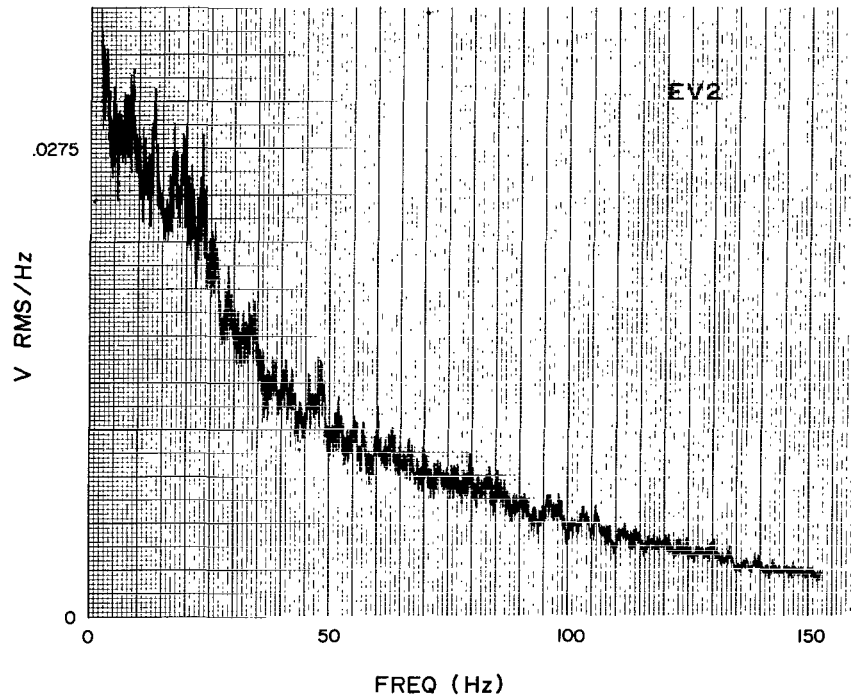


FIGURE 17. EXAMPLE OF TYPICAL CURVE - CASE I.

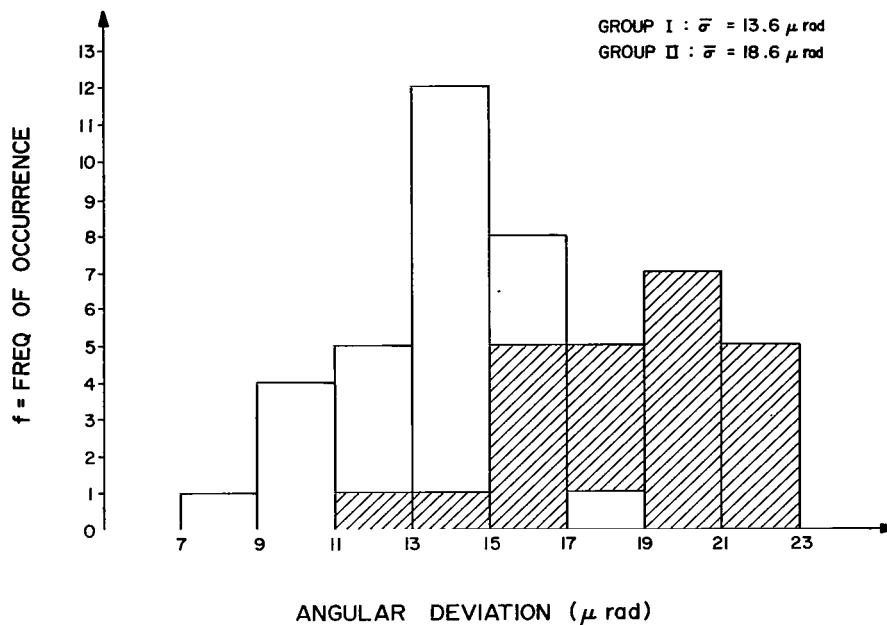


FIGURE 18. FREQUENCY HISTOGRAM OF GROUP I AND II OVERLAP - CASE I.

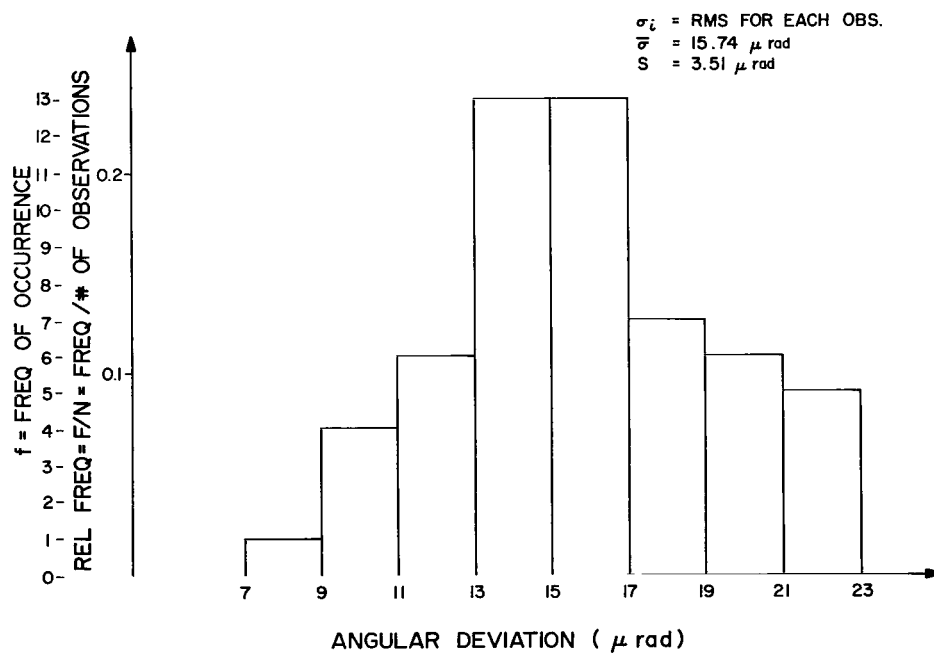


FIGURE 19. FREQUENCY HISTOGRAM OF COMBINED OBSERVATIONS - CASE I.

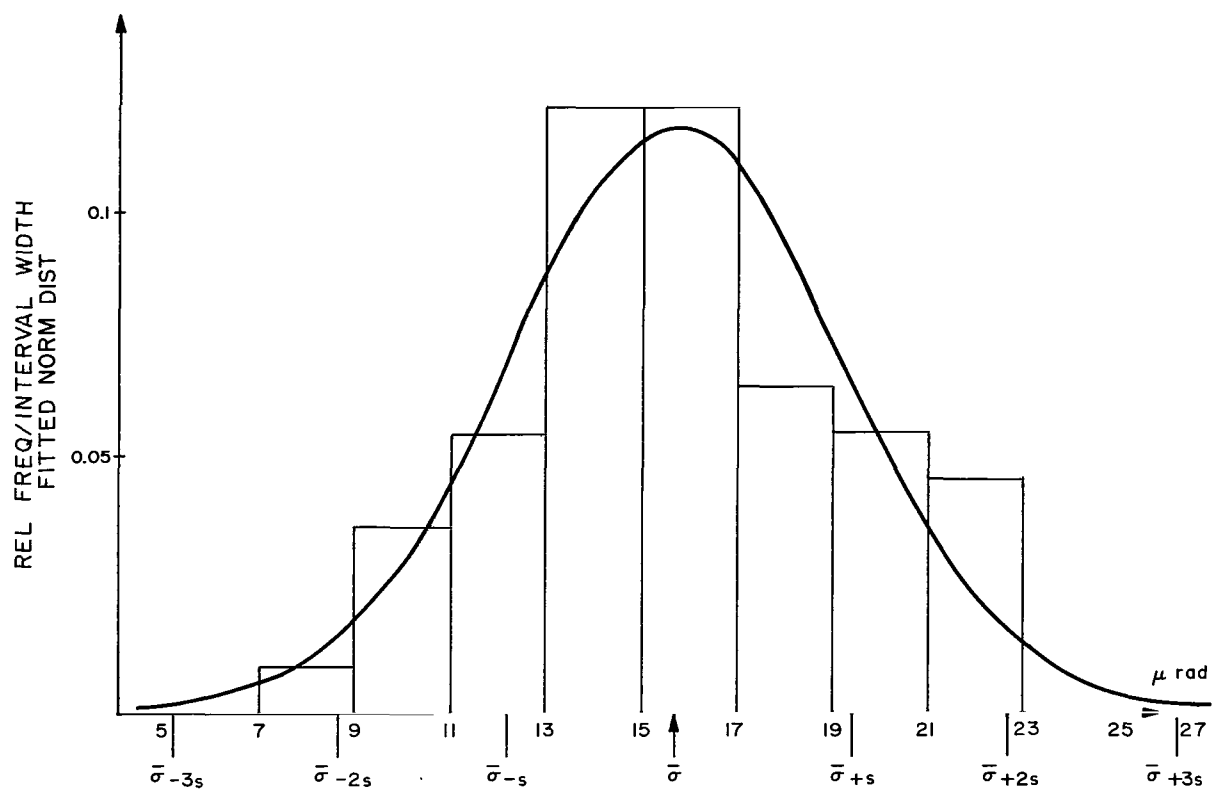


FIGURE 20. FITTED NORMAL DISTRIBUTION - CASE I.

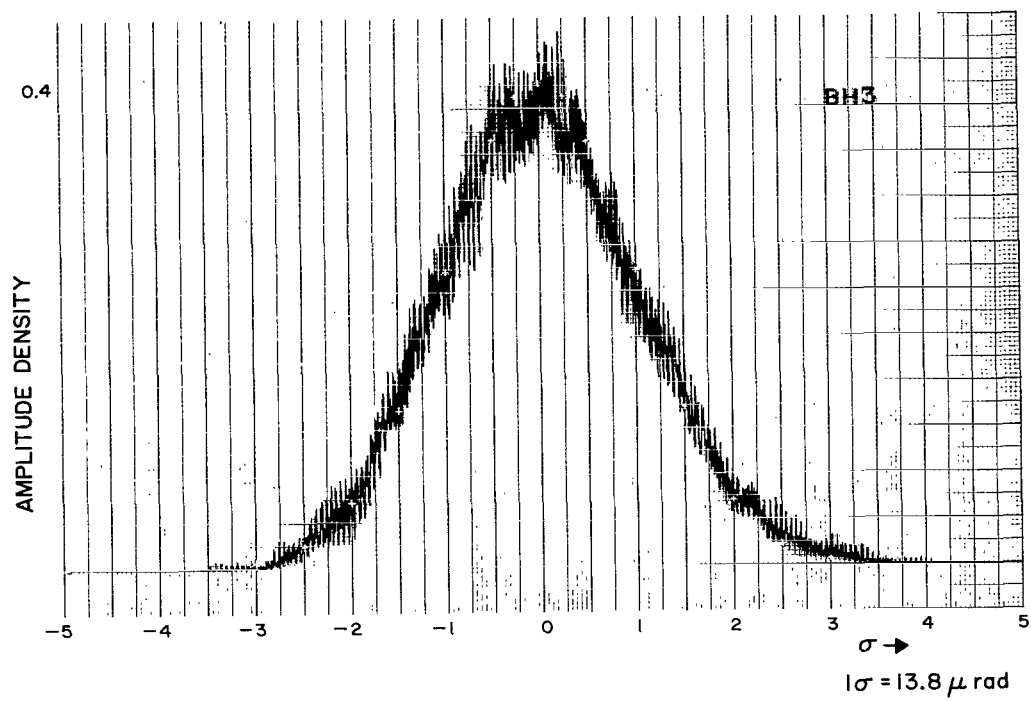


FIGURE 21a. TYPICAL AMPLITUDE DENSITY CURVE - CASE I.

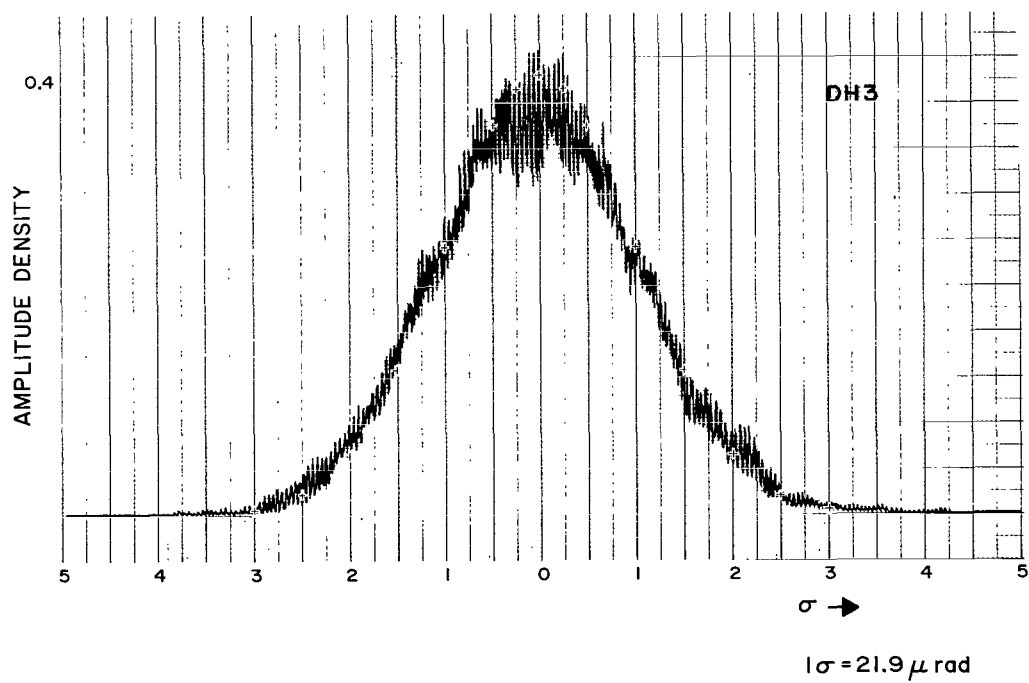


FIGURE 21b. TYPICAL AMPLITUDE DENSITY CURVE - CASE I.

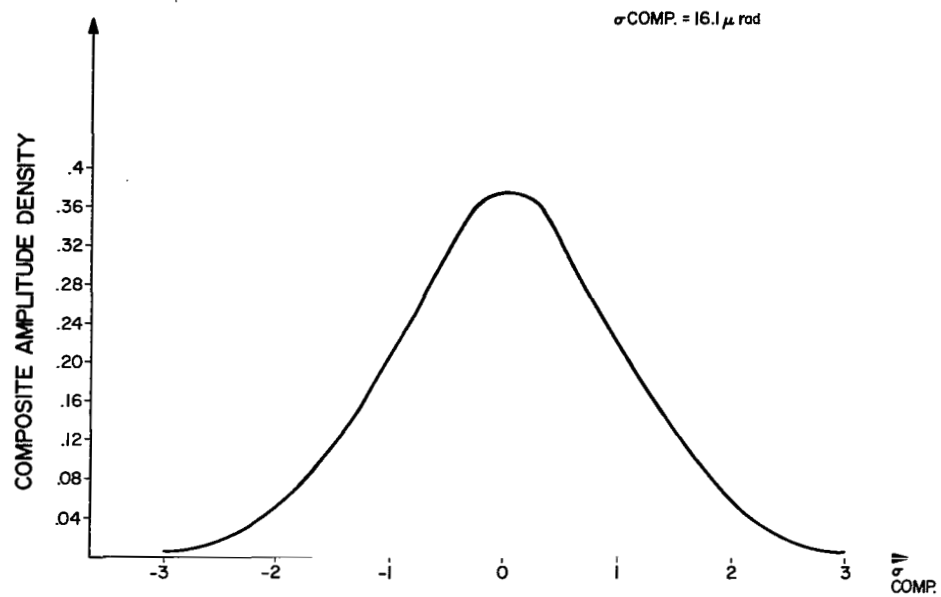
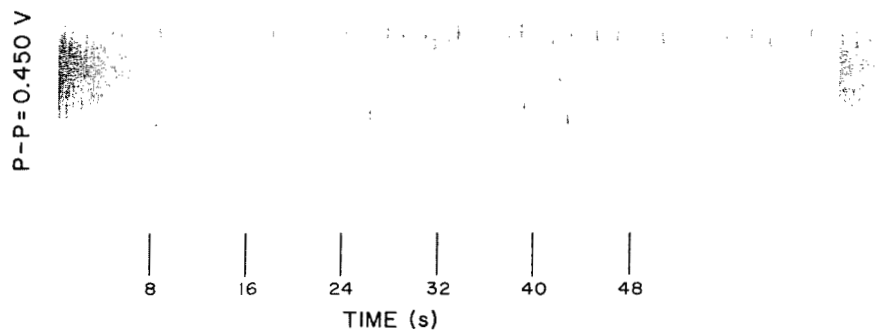


FIGURE 22. COMPOSITE AMPLITUDE DENSITY - CASE I.

H17



V5

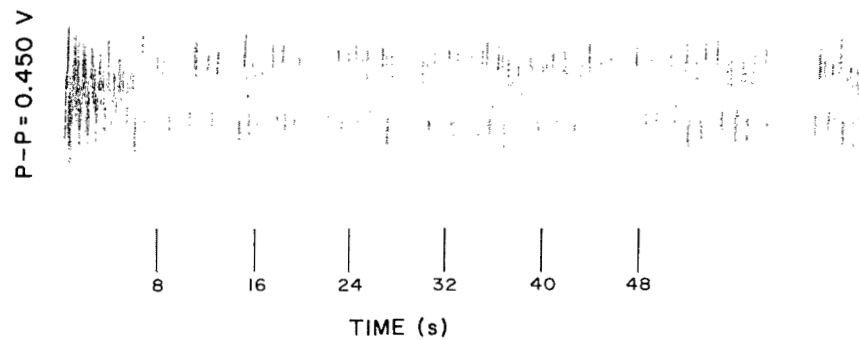


FIGURE 23. RAW DATA OSCILLOGRAPHS - CASE II.

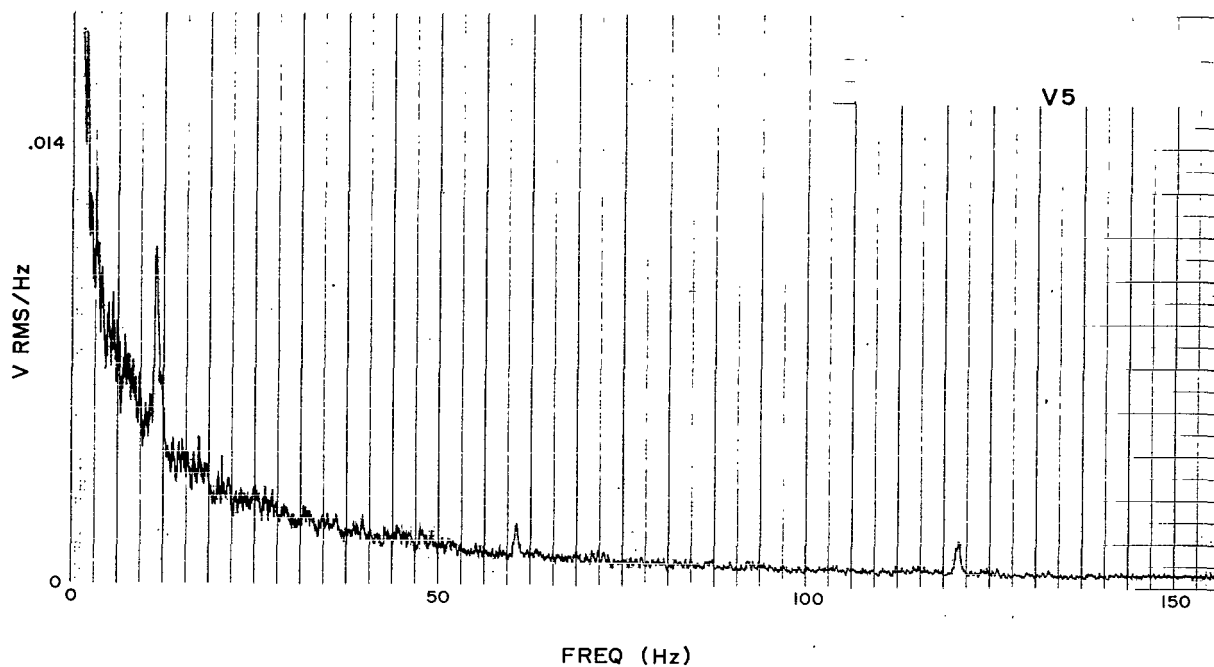


FIGURE 24. TYPICAL AMPLITUDE VS. FREQUENCY CURVE - CASE II.

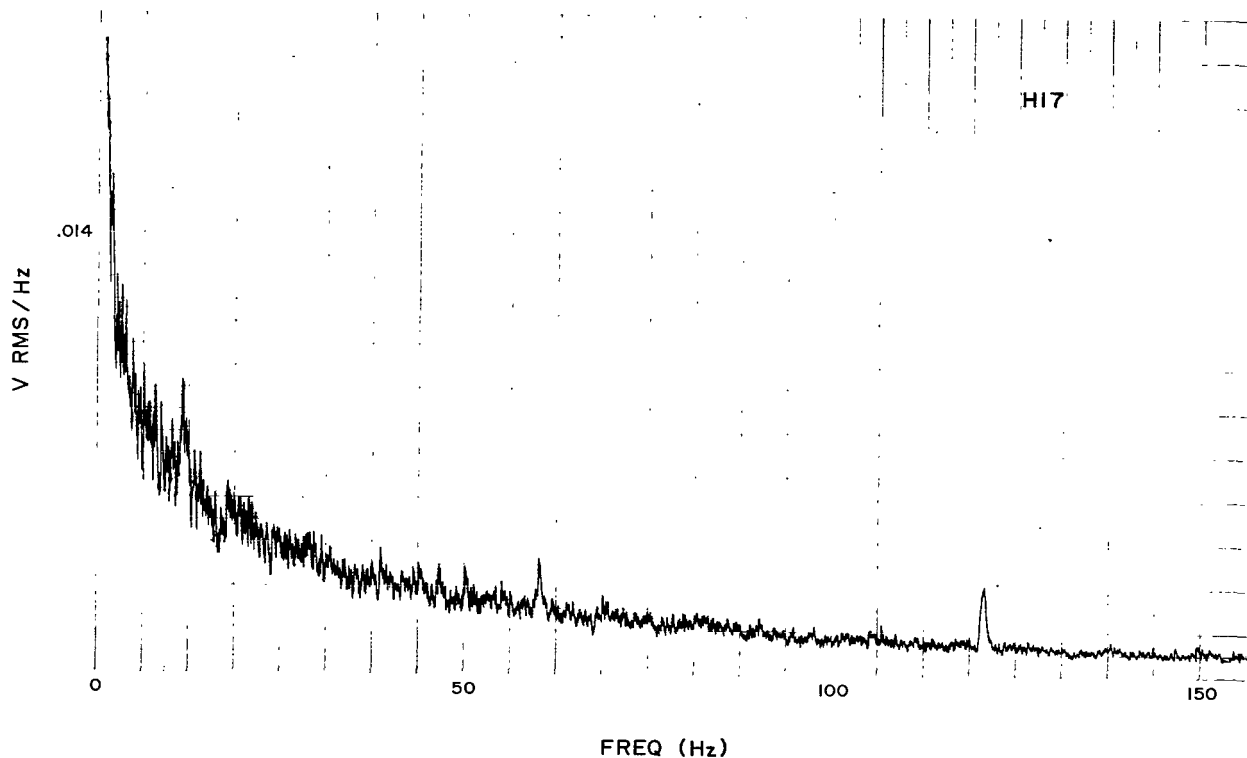


FIGURE 25. TYPICAL AMPLITUDE VS. FREQUENCY CURVE - CASE II.

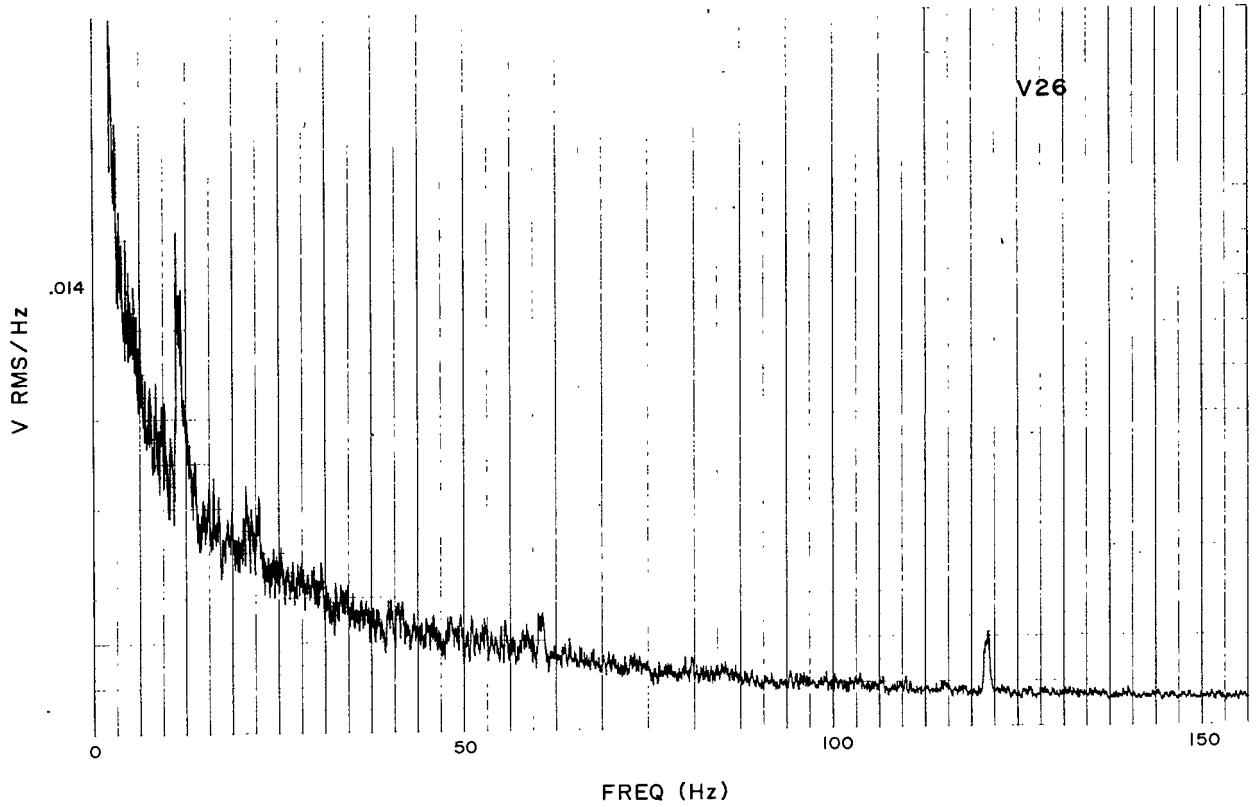


FIGURE 26. TYPICAL AMPLITUDE VS. FREQUENCY CURVE - CASE II.

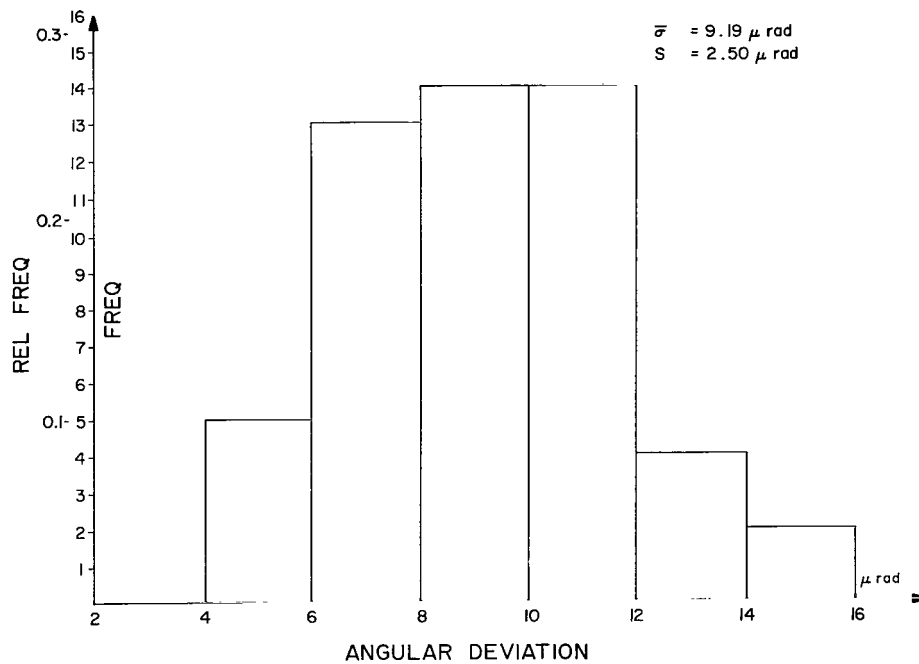


FIGURE 27. FREQUENCY HISTOGRAM - CASE II.

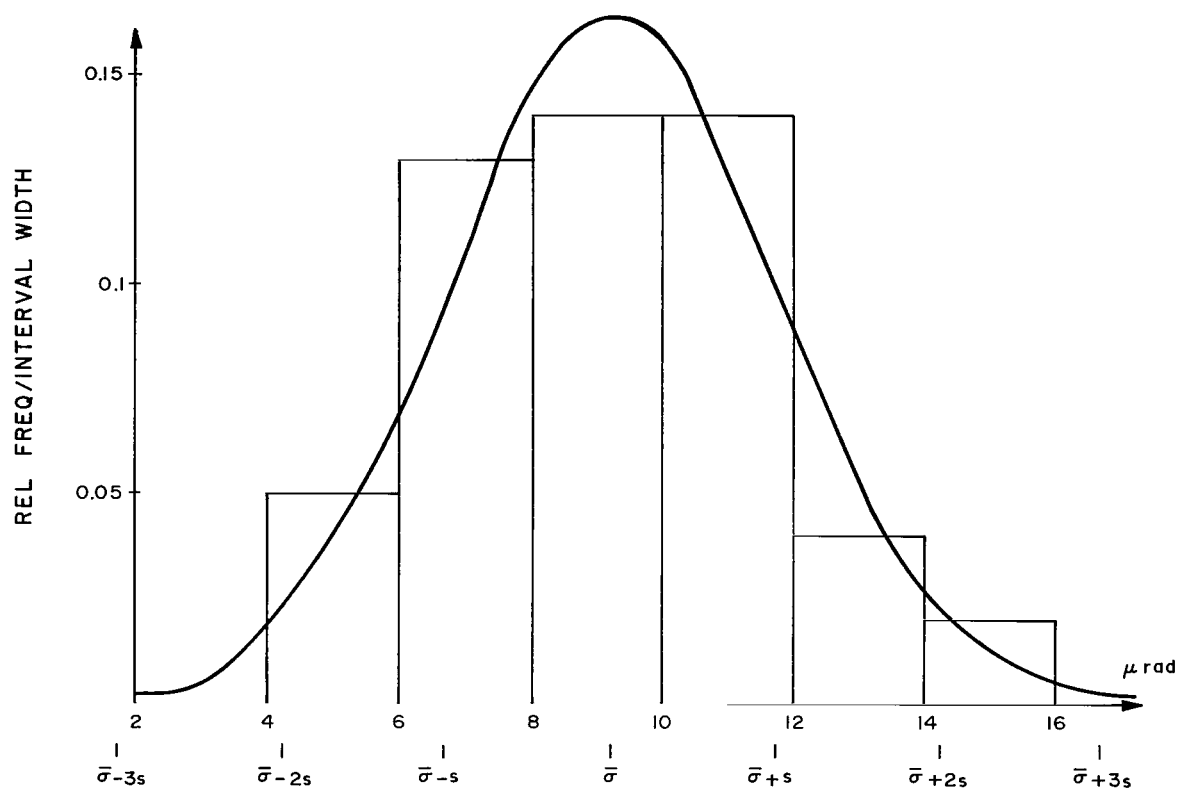


FIGURE 28. FITTED CURVE - CASE II.

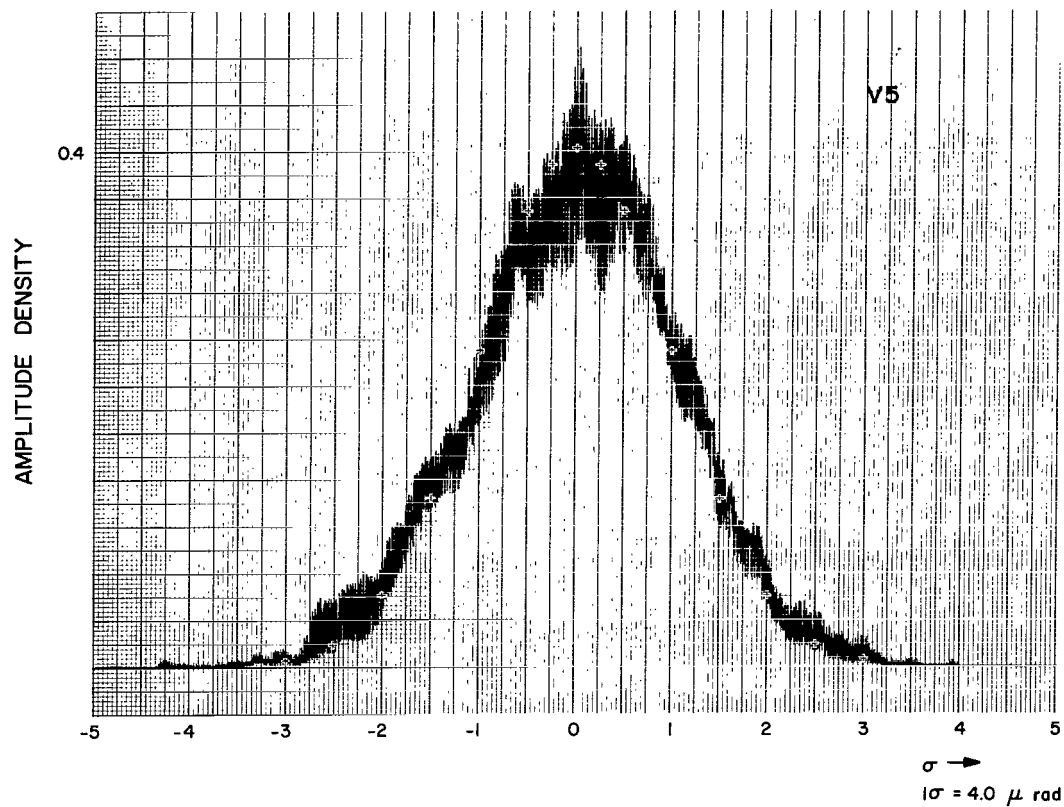


FIGURE 29a. TYPICAL INDIVIDUAL AMPLITUDE DENSITY CURVE - CASE II.

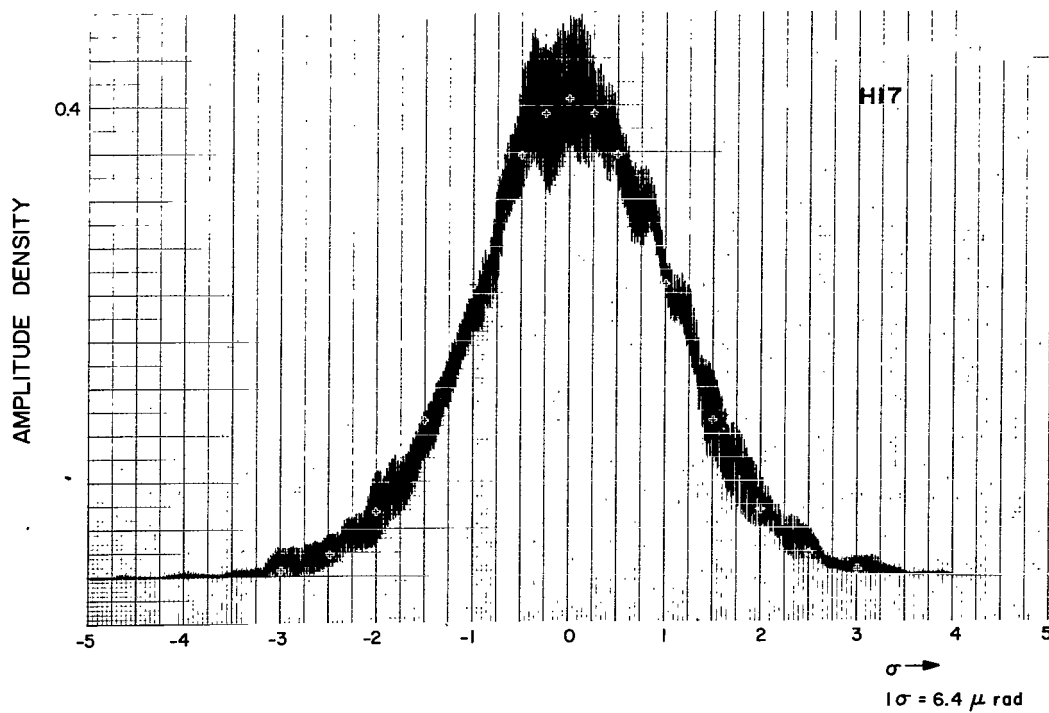


FIGURE 29b. TYPICAL INDIVIDUAL AMPLITUDE DENSITY CURVE - CASE II.

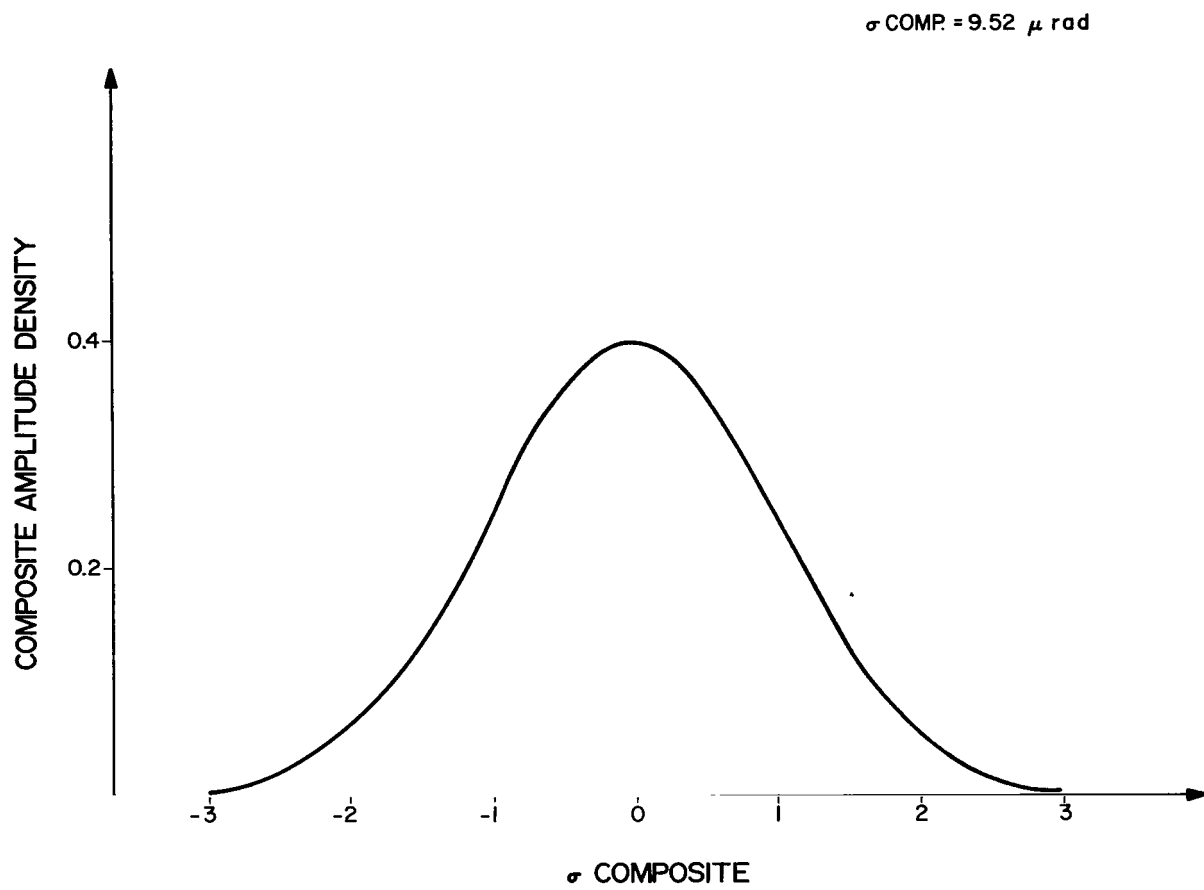


FIGURE 30. COMPOSITE AMPLITUDE DENSITY - CASE II.

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